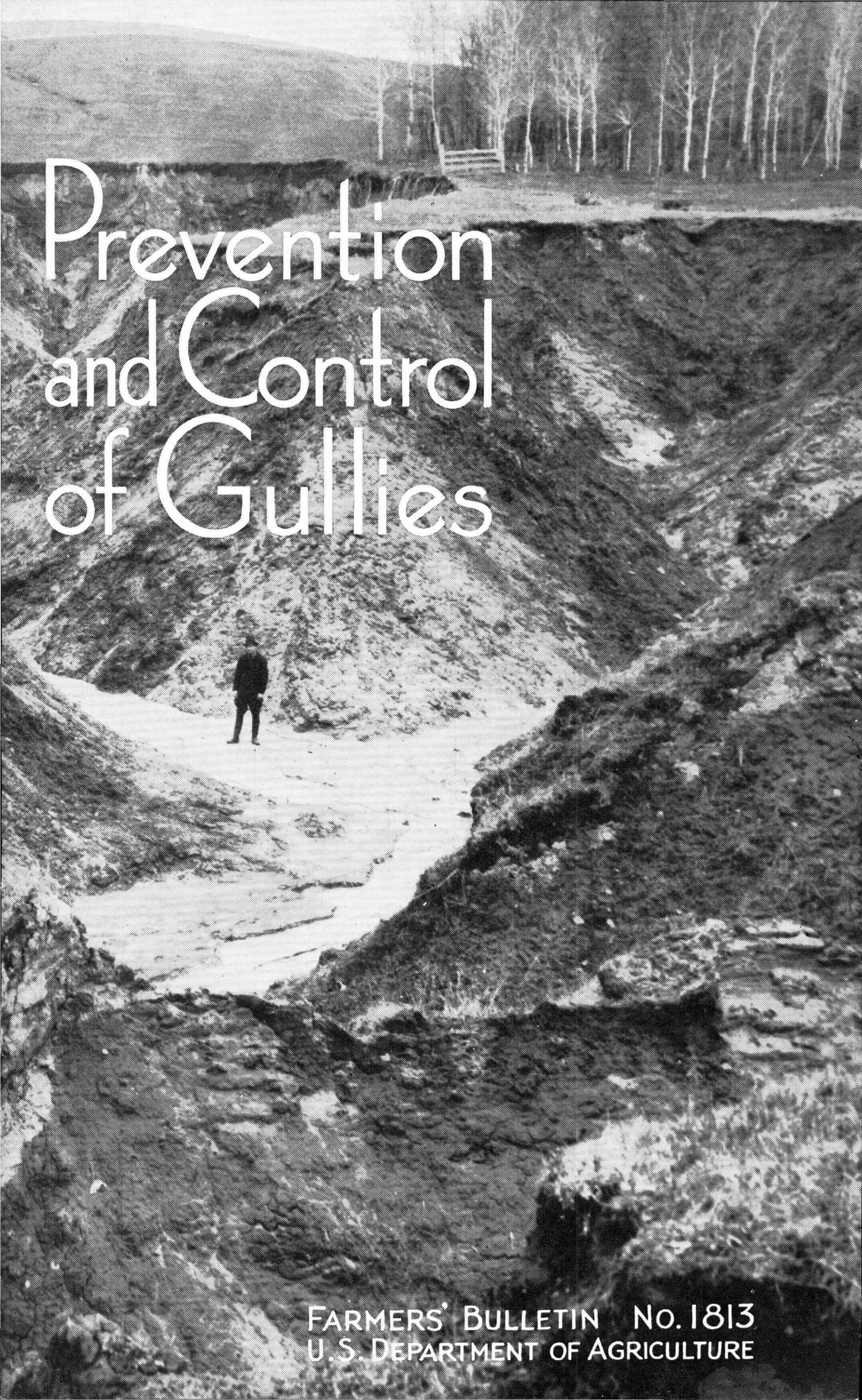
Prevention and Control of Gullies



FARMERS' BULLETIN No. 1813
U. S. DEPARTMENT OF AGRICULTURE

IT IS A COMMON CONCEPTION that gully control means building check dams, planting trees, plugging gullies with brush, or directly applying to a gully some other individual control measure. This way of thinking focuses attention on devices that stop gullies rather than on ways of farming that prevent gully erosion. It overlooks the limitations of trying to check gullies by some individual control measure and neglects the necessity of properly coordinating means of control. Uncoordinated individual control measures frequently lead to wasted effort, unnecessary expenditures, and disappointment in the performance of the controls used.

A broad, coordinated attack is in general necessary to keep gully erosion under control. A farmer who wishes to keep his fields free from gullies must give first consideration to proper land use and conservation farming on areas that contribute run-off to the gullies. He must have an understanding of the best way to take care of the run-off from those areas. He will make wide use of vegetation in replanting gullies and will therefore need information on the selection of vegetation best suited to local field conditions. He will want to know the particular uses to which plants can best be put and how vegetation can be successfully maintained.

To provide general information useful in such an approach to gully control is the purpose of this bulletin. It describes various types of treatment and states the principles that should be considered in selecting and using these means of saving the land from gullying. It shows how gully-control measures can be used effectively in coordination with recommended soil and water conservation practices.

This bulletin supersedes Farmers' Bulletins 1234, Gullies, How to Control and Reclaim Them; 1697, Using Soil-Binding Plants to Reclaim Gullies in the South; 1737, Stop Gullies: Save Your Farm; and 1760, The Use of Bluegrass Sod in the Control of Soil Erosion.

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PREVENTION AND CONTROL OF GULLIES

By Hans G. Jepson, *assistant agricultural engineer, Engineering Division, Soil Conservation Service* [1]

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WHAT GULLIES DO

"SINCE THE ACHIEVEMENT of our independence, he is the greatest patriot who stops the most gullies." If this was true 150 years ago, when Patrick Henry made this statement, it is doubly true today. For gullies are now destroying land in every State. They have eroded many fields so badly that it has been necessary to discontinue the cultivation of areas that were good farm land only a few years ago. Year after year fields are abandoned as the old gullies take more of the land and new ones form.

When lands are gullied, the fertile soil is carried away, and unproductive soil may be deposited on rich bottom lands. Reservoirs and channels are also silted up, which then have to be dredged at great expense. Gullies that cannot be crossed readily by teams and farm machinery divide fields into smaller units and thus increase the cost of cultivation. As gullies tend to drain adjacent soil of its moisture, fields dry out much more rapidly near the gullies. This reduces crop yields on these fields. As these gullies become larger they branch out over the fields; and if they are allowed to develop unchecked, entire fields may have to be abandoned.

Gullies encroach upon public highways; undermine fills, bridges, and culverts; increase maintenance costs; and make travel unsafe. Livestock grazing near the edge of undermined gully banks is endangered. Gullies occasionally extend through a farmstead, undermining the farm buildings and making it necessary to remove them. The unsightly appearance of a gullied farm reduces its market value. These destructive and unsightly ditches have already caused damage

[1] This bulletin has been prepared in cooperation with C. L. Hamilton and under the general supervision of T. B. Chambers, in charge, Engineering Division. All members of the engineering division, and particularly G. E. Ryerson, have submitted valuable comments and criticisms. The divisions of agronomy, wildlife, and woodland management contributed to parts of the bulletin relating to their respective fields. The earlier gully-control studies of C. E. Ramser have been extensively used as well as material contributed by field engineers of the Soil Conservation Service.

that amounts to millions of dollars—much of it a needless loss, had attention been paid to the things that give gullies their start.

HOW GULLIES START

Before we destroyed the native timber, plowed up the virgin sod, and allowed large herds of sheep and cattle to overgraze the range erosion was not a serious problem. Under nature's cover of vegetation the soil absorbed much of the rainfall and was protected from excessive erosional losses.

In order to make way for the production of crops the land was cleared and plowed. No precautions were taken against loss of soil. On sloping fields the rows were run regardless of the direction of the slope. As a result the amount and velocity of run-off increased until it readily carried away large quantities of soil. At first the soil was removed from the surface in very small rivulets. They gradually became larger, and eventually gullies were formed, which enlarged with each succeeding rain that produced run-off.

Wherever the natural protection of the land is destroyed, the soil is made more vulnerable to erosion. Natural drainageways covered with vegetation once carried the run-off from the land. Stripping these drainageways of their natural cover and cultivating across them (fig. 1, *A*) or subjecting them to other undesirable farming practices is the beginning of many gullies. Steep slopes cleared for cultivation (fig. 1, *C*) will soon be badly gullied.

Poorly placed or poorly protected outlets for farm-drainage systems or improperly designed irrigation channels are points where many gullies begin. Improper location and protection of drains for farm roads or highway systems are an invitation to a gully to take the adjacent land. Trails or ruts over sloping fields (fig. 1, *B*), also contribute to some extent to the formation of gullies. The diversion of run-off into drainageways that are not well enough protected to carry the additional load is one of the surest ways to give gullies a start.

TYPES OF GULLYING

The careless use of land makes it possible for gullies to form. Gullying proceeds by waterfall erosion, channel erosion, erosion by alternate freezing and thawing, or a combination of these three types. Each type of gullying has a characteristic form (fig. 2), which may be modified to a considerable extent by local soil characteristics. If the underlying soil materials are soft and easily incised, deep, straight-walled gullies are formed; if the subsoil consists of plastic, resistant clays, the gullies are relatively shallow with sloping banks.

WATERFALL EROSION

Water falling over the edge of a gully or the bank of a ditch forms deep and very rapidly extending gullies. Their characteristic form is a U-shaped cross section (fig. 2, *A*).

A small vertical overfall usually develops in the lower reaches of a drainageway, and water falling over it undermines the edge of the bank, which caves in, and the waterfall moves upstream. As the overfall advances up the slope its vertical height increases, since it usually leaves a relatively flat slope below. This undermining goes

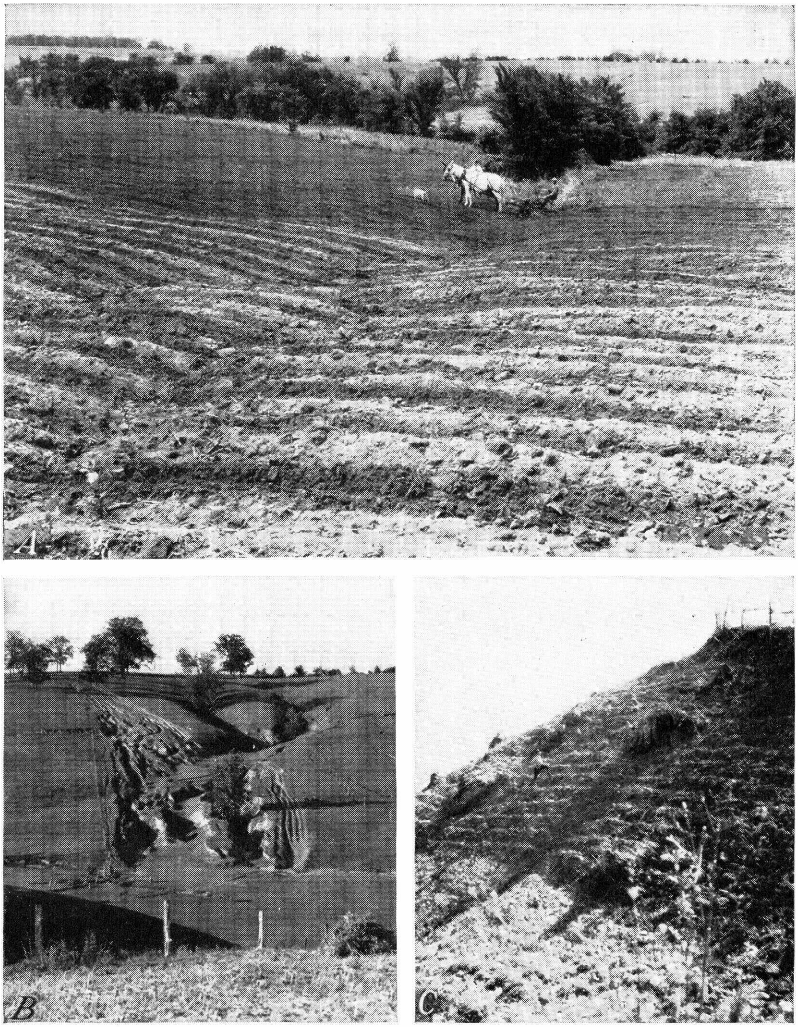

FIGURE 1.—*A*, A gully is gradually forming in this drainageway. If seeded down and left permanently in grass, the drainageway would carry run-off from the field without gullying. *B*, Sheep traveling up and down the slope made the paths that gradually developed into these gullies. Shifting or rearranging pasture lanes would have prevented this. *C*, Continued cultivation of this hillside will run gullies down the slope. Land as steep as this should be left in permanent cover.

on rapidly, particularly if the surface soil is underlain by sand or easily eroded subsoil.

In this manner gullies often start in the bank of natural watercourses that have been eroded to a great depth. They extend back into the drainage area and grow deeper up the slope, often attaining depths of 50 to 60 feet or more. As they extend backward and cross lateral drainageways or natural depressions, waterfalls are in turn formed in the sides of these depressions, and branch gullies develop. This branching may continue until a network of gullies covers the entire

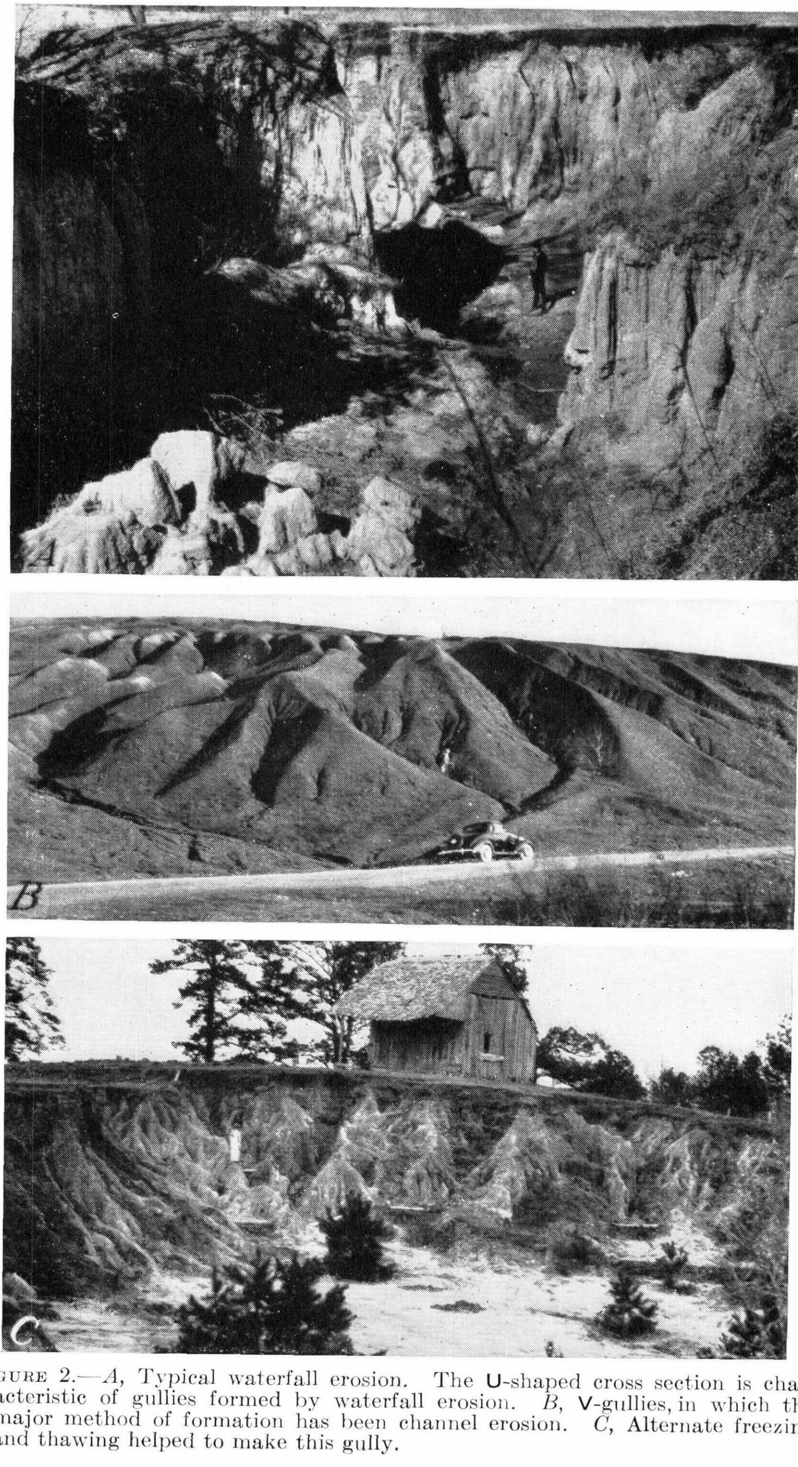

FIGURE 2.—*A*, Typical waterfall erosion. The U-shaped cross section is characteristic of gullies formed by waterfall erosion. *B*, V-gullies, in which the major method of formation has been channel erosion. *C*, Alternate freezing and thawing helped to make this gully.

drainage area. Their growth is dependent mainly on soil characteristics, depth of overfall, and the size of the contributing drainage area rather than on the slope of the land. They may extend very rapidly even through almost level land. They frequently grow at a rate of 30 to 50 feet a year, depending on the amount of run-off and the character of the soil. Some of them have been known to advance several hundred feet during a single heavy rain.

In the Pacific Southwest some of the larger gullies formed in this way are known as barrancas; in the Northwest they are called coulees; in the Colorado Basin they are commonly referred to as arroyos or washes.

CHANNEL EROSION

Channel, or ditch, erosion is essentially a scouring away of the soil by concentrated run-off as it flows over unprotected depressions. Gullies formed by channel erosion usually have sloping heads and sides (fig. 2, *B*). In fact, these gullies are often referred to as V-gullies. As the scouring continues the gully becomes longer, deeper, and wider. V-gullies often attain lengths of 1 mile or more and depths and widths of 20 to 40 feet. The extension in length is usually much faster than the widening of the gully because a greater volume of run-off passes over the gully head than over the sides. Usually the gully does not advance beyond the divide of the drainage area, but it may continue to widen and deepen for years. The rate at which the gully deepens is very rapid on the upper part of the area, where the slopes are comparatively steep, and generally it decreases in the lower reaches as the slope decreases. Silting, rather than erosion, may occur if the channel or ditch emerges into a wide, flat-bottom drainageway. The increased volume of water, however, may offset the effect of moderate changes in slope along the lower reaches.

Channel erosion and waterfall erosion are commonly found in the same gully. The extension of the vertical head is usually by waterfall erosion; and the scouring of the sloping bottom and sides by channel erosion extends the depth and width. Gullies frequently start by channel erosion, and as an overfall develops at the head of the gully, the gully continues to develop by waterfall erosion. Gullies formed by channel erosion alone are often a series of closely spaced, parallel, V-shaped gullies in the upper reaches of drainage areas, where slopes are fairly steep and the contributing area small. Channel erosion is usually present in gullies caused by waterfall erosion, except those newly formed.

EROSION BY ALTERNATE FREEZING AND THAWING

Erosion by alternate freezing and thawing is prevalent in parts of the South, where alternate freezing and thawing temperatures are common in the winter and precipitation is generally in the form of rain. Alternate freezing and thawing loosens the soil, which sloughs off and is then carried away by heavy rains. This occurs on all slopes of a gully bank (fig. 2, *C*), and particularly on southern exposures. Gullies formed in this way may extend in all directions, as the direction of growth is not determined by the slopes of a field. Gully erosion by alternate freezing and thawing usually supplements waterfall and channel erosion, particularly in the Southern States. It may continue for years as the only form of erosion in gullies that are near a drainage divide and have little or no contributing drainage area.

In certain localities, during or immediately following prolonged rains, and especially following periods of alternate freezing and thawing, mass movements of soil in the form of slides, earth flows, and slumps take place on steep slopes. A considerable number of gullies have their beginning in these disturbed or galled areas, particularly where the displacement exposes highly erodible subsurface material. These mass movements usually develop conditions that are conducive to gullying.

PREVENTION OF GULLIES

This bulletin deals with the control of gullies that begin as a result of man's abuse of the land. We can prevent these gullies. To prevent the formation of a gully is much better and easier than to control it once it has formed. We can never prevent erosion entirely

FIGURE 3.—A permanent meadow strip left as a drainageway. Even though the slope is steep, this drainageway will carry run-off with little danger of gullying.

because natural deterioration will continue as long as there is action by wind, water, or frost. But this natural geologic erosion is generally so gradual and moves at so slow a pace that it does no appreciable harm.

It is the erosion that arises from improper land use and methods of tillage that those who work the land can control. If a farm is free of gullies (fig. 3) it will usually be found that the operator, under a well-developed land use program, uses good farming methods and is constantly on the alert against gullying. Wherever and whenever he finds a danger spot he immediately takes steps to prevent the formation of a gully. It is easy to stop a gully when it has just begun to form, but if the gully is neglected for some time it can usually be checked only with considerable work and at no little expense. It should not be assumed, however, that just because no gullies are visible on a field no erosion is taking place. There may be considerable sheet erosion, which is a forerunner of gullying unless it is checked.

Constant vigilance is necessary to forestall gullying that starts from some practice that may seem of no consequence. The thoughtless driving of a wagon up or down a slope in a field made soft by rain leaves a deep rut that may develop into a large gully unless it is in some way filled in immediately. Filling the rut with straw or manure, or even spading it full, will usually prevent further damage.

Many farms have deep gullies because the feed lots were not properly located or because the stock trails cut deep into sloping pasture lanes (fig. 1, *B*). Such gullies can usually be prevented by shifting fences as need arises and by rotating feed lots if gullies should begin to form. Care should be used in the location and protection of drainageways, of watering places for livestock, and of roads or trails.

Unless caused by such minor things as drain outlets or stock trails, gullying is usually preceded by sheet erosion. A close examination of sheet erosion shows that the soil is not removed in strictly uniform sheets or layers, as is so often supposed, but that numerous small rivulets are formed, which might be classified as miniature gullies. They are so small and close together that this process of soil removal is usually spoken of as sheet erosion. When water from several of these rivulets collects, larger depressions are formed, and they may finally become gullies. It thus is evident that where heavy sheet erosion has been under way for a period of time, gullying is probably imminent. Little sheet erosion occurs on a farm if its steep slopes are covered with trees and shrubs, its flat land and moderate slopes farmed according to approved cropping and tillage practices, and intervening areas reserved for permanent grasses (fig. 4).

The first step in preventing gullies is to plan or replan the farm so as to get the best possible use of the land. This will include the retirement to permanent cover of such areas as are definitely too steep to farm; the utilization of the better agricultural land for cultivated crops; the placing of moderately sloping and eroded areas in meadow or pasture, if such areas cannot be economically tilled. Good land use may require that the general field pattern be considerably changed and only the most suitable areas used for crops. In many instances fences will have to be reset and field roads rerouted to get the best arrangements.

The best known methods of controlling erosion on those slopes that must be tilled are crop rotations, cover crops, strip cropping, and contour cultivation, alone or in combination with terracing where it is required. These practices are discussed in Farmers' Bulletins 1776, Strip Cropping for Soil Conservation; 1758, Cover Crops for Soil Conservation; and 1789, Terracing for Soil and Water Conservation. Insofar as the methods of farming described in these bulletins control erosion they aid directly in preventing the formation of gullies. The use of fertilizers and the conservative grazing of pasture or range also protect the land from erosion.

One of the most important considerations in land use that prevents gullies is the proper disposal of excess run-off water from the fields. Every farm has its own natural drainage pattern, which, in general, it is difficult to change. This pattern includes all water-conveying depressions or channels of either continuous or intermittent flow. Except for minor variations it should be followed in planning fields and, especially, in locating outlets for terraces or diversion ditches.

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Natural drainageways should be used, wherever possible, and they should be left in sod in order that they may continue to carry water without gullying. The extra ground that may be cropped by farming these drainageways can in no way compensate for the damage that will occur if severe gullying is begun by cultivating the drainageways with the rest of the field.

If the general drainage pattern is not considered or followed in planning for land use, either a very expensive artificial system to dispose of surplus run-off will be required or the water must be concentrated in undesirable locations that will eventually gully. If a

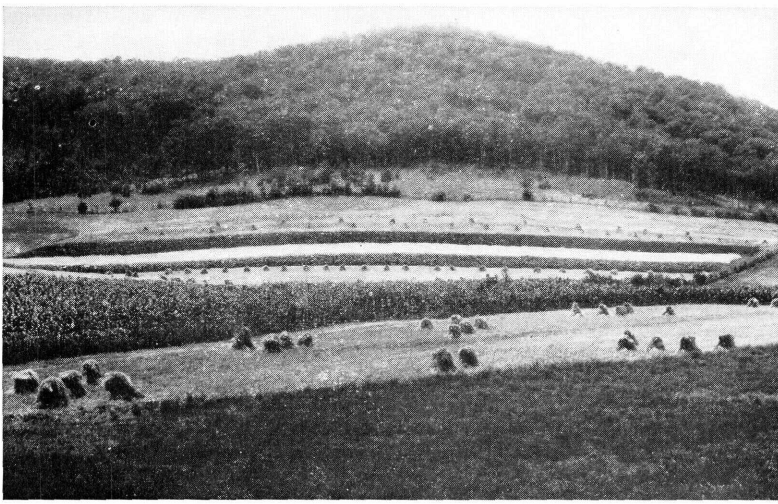

FIGURE 4.—Where there is proper land use there are few gullies. The steep upper slopes have been left in woods, the lower slopes are in meadow or permanent pasture, and the bottom land is strip-cropped.

natural drainage unit is not complete on one farm, but covers two or more farms, a better water-disposal plan can be worked out if the farms are considered collectively.

If the results of careless cultural practices could have been foreseen or if just a little time had been spent in checking the beginning of a small gully, many of the present large gullies would never have formed. Once the gullies have formed and prevention is too late, it is still possible to stop serious erosion in the gullies and cover most of them with vegetation.

PLANNING GULLY CONTROL

LAND USE AND CONTROL COSTS

The size of both the gully and its drainage area are of great importance in planning the control of gullies. In order to avoid confusion as to what will be considered large or small gullies, it seems desirable to classify them. The differences of opinion as to size groupings makes such classification difficult. A large gully in the northeastern part of the United States may be considered a medium-sized gully in the Southeast. The following classification of gullies according to size is suggested for general use. The range of these groupings is necessarily

wide in order to accommodate the wide variations in field conditions.

Small gully: Less than 3 feet deep.
Medium-sized gully: Three to 15 feet deep.
Large gully: Over 15 feet deep.

It is recommended that gullies be further classified according to the size of their drainage area. A small drainage area is 5 acres or less; a medium-sized drainage area, 5 to 50 acres; and a large drainage area, over 50 acres. According to this classification a small gully with a medium-sized drainage area is a gully less than 3 feet in depth with a watershed of 5 to 50 acres.

If a gully directly menaces a building or a highway structure it is a rather simple matter to determine how much money may be spent to protect this property as its value is usually known or can be readily estimated. Estimating the damage of gullying in a field or the justifiable expenditure for checking it is not so easy, as it is much more difficult to determine the true value of the land and the exact extent of present and ultimate damage.

"How much am I justified in spending?" This is the first question every farmer asks himself when he plans to stop gullying on his land. If a gully has already advanced within a short distance of its drainage divide it may be unwise to spend very much in controlling the gully because it can do only a little more damage. After a gully has eaten its way to the head of the watershed it usually ceases to be active, and if it is protected from livestock, natural revegetation will reclaim it over a period of time. If a gully has advanced only a short distance into the watershed there is more justification for establishing immediate control (fig. 5).

The actual acreage of the land surface destroyed by a gully may be relatively small, but this gully may so dissect a field or threaten adjacent areas as to hamper or endanger farming operations on the entire watershed, either immediately or in the future. And just one badly gullied field on a farm creates an unsightly appearance that reduces the value of the entire farm. The value of a farm on which gullying is active may therefore decrease much more rapidly than the present state of gullying would indicate.

Although severely gullied land has little immediate value some control measures are usually warranted on all such areas if only to protect adjacent lands. But it is well to determine what is the most economical and suitable protection for each gullied area. The cost of controlling a gully and the type of protection should always be considered in relation to the use that can be made of the gullied land as well as the protection to adjacent areas that such control will afford.

For example, a badly gullied field that could not be restored to usefulness as cropland except at too great expense may be retired to woodland, for which purpose it may have considerable value. If this is done, little expenditure for gully control need be made because a protected plantation over the larger part of the drainage area will ordinarily prevent further gullying.

Less seriously damaged areas may be used for permanent pasture or meadow, provided a suitable cover can be established and the cost of controlling the gullies can be kept commensurate with the returns to be expected from the land. Land that is to go into permanent pasture or meadow often requires considerable treatment to provide a satisfactory grass cover and to facilitate future farming operations.

More expensive gully treatment is usually required on gullied land to be retained for crops, but the fertility or value of the land may justify it. In general, however, it may be said that complete, immediate reclamation of gullies is too costly unless the gullies are still so shallow that they can be crossed with machinery or terraces. The expense of installing the control measures necessary to check gullies on highly erodible areas to be kept in cultivation is frequently considerable. On these areas it is usually more economical to check active erosion within the larger gullies and then reclaim the gullies over a period of years through the use of vegetation.

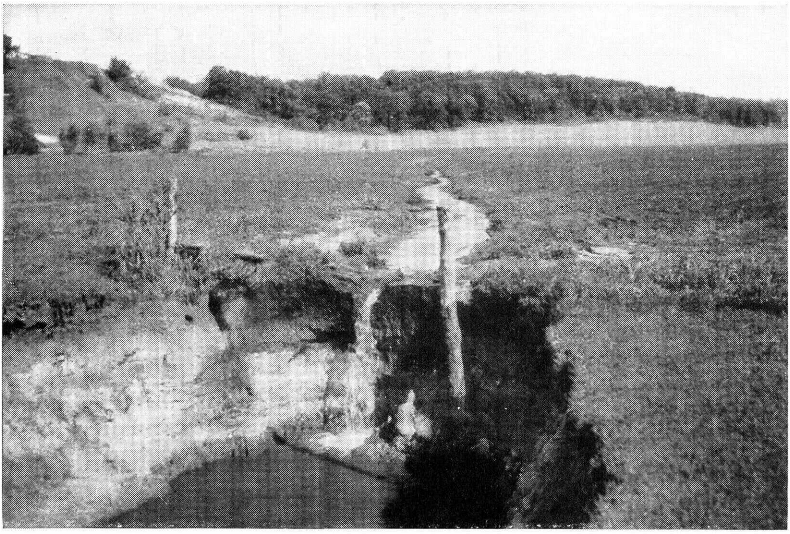

FIGURE 5.—This gully head is just beginning to eat its way across a cultivated field. It can still be controlled with relatively low cost. If allowed to erode unchecked, it will advance across the entire field. A gully has no respect for fence lines as is evidenced by the fence post dangling in mid-air. Note the steep banks along the gully head. This is an excellent example of waterfall erosion.

There is a special type of treatment in gully control that is peculiar to the arid and semiarid parts of the United States. It has been used on large barrancas and arroyos in locations where land values are high or where it has been found necessary to protect reservoirs and irrigation systems from excessive silting. For example, where a large gully is biting into valuable orchard land it may be justifiable to fill the gully completely through the use of one or more silt-retention dams. These dams can also be used if silt deposits are being carried into irrigation systems by an actively cutting gully, even though the gully head may be under control. The silt load can be materially reduced by placing large multiple-lift, overpour dams in the alluvial-fill valleys. These structures are located at sites where the grade of both the gully and valley floor is mild and where the valley floor is sufficiently broad to permit the spreading of water. When properly located, these dams serve to stabilize active lateral cutting and they will gradually rebuild the gully by collecting silt. They often serve the twofold purpose of holding back silt and providing water for supplemental irrigation.

TREATMENT OF GULLIED DRAINAGE AREAS

Complete gully control includes proper treatment of the drainage area as well as of the gully itself. If the control treatment is applied only to the gully, it is likely that all control efforts are being directed at the results and the cause neglected. Neglecting the drainage area usually makes it much more difficult, if not impractical, to control a gully satisfactorily and often leads to the formation of new gullies faster than the older ones can be checked. For example, if an eroding field is terraced and nothing further is done to control erosion on adjacent fields it is likely that gullies will gradually encroach upon the terraced field and damage it.

If a drainage area is gullied, it will require more complete treatment than if the gullies were not present. For example, regular cropping and tillage practices that conserve the soil may permit the safe production of farm crops on an ungullied drainage area, but if gullies are present it may be necessary to put a permanent cover of vegetation on the area. Or a relatively flat, ungullied drainage area may be cropped without excessive soil and water losses if only crop rotations, contour tillage, and strip cropping are practiced, whereas the presence of a few gullies on that area would make it necessary to use terraces in addition to these other conservation practices if the same crops were to be produced without excessive soil loss and further gullying checked.

The plan of treatment for gully control, in order to be complete, should thus include treatment of the drainage area based on good land use and soil- and water-conserving practices such as strip cropping, contour tillage, crop rotations, and cover crops. These should be combined with terracing or contour furrowing where applicable. Only in this way is it possible to achieve a measure of success in the control of gullies or any assurance that such control will be more than short-lived.

ESTIMATING RUN-OFF

A soil can absorb rainfall up to a certain rate. When this rate is exceeded some of the water begins to run off. That is why heavy and rapid downpours are much more likely to cause harmful erosion than equivalent amounts of rain that fall over longer periods. This fact is so generally understood that special terms have come into use to express this relation. For example, a slow, steady rain is ordinarily called a "ground soaker," and a dashing downpour is commonly referred to as a "gully washer." The more rapid the rate of rainfall, other conditions being the same, the greater the proportion of rain lost as surface run-off.

It is the run-off that loosens the soil and carries it away. Without run-off there would be no gully erosion. Furthermore, the degree of gullying is directly associated with the rate of run-off. A high rate is usually more destructive than a low rate. The rate of run-off is generally a more accurate indication of the probable damage that run-off will cause than the amount of run-off. The rate of run-off is dependent on the size, shape, and slope of the drainage area; the extent, nature, and condition of the soil and cover; the intensity and duration of the rainfall; and the slope and condition of the drainage channels. High rainfall intensities of long duration, poor plant cover, saturated, frozen, or impervious soils, and steep slopes all contribute to high run-off rates.

One must estimate the probable rate and amount of run-off from a

TABLE 1.—*Run-off from drainage areas*[1] *of 1 to 300 acres, based on a 10-year rainfall intensity-frequency*

Watershed characteristics[2]	Group[3]	Run-off from drainage areas of— 1 acre	2 acres	3 acres	4 acres	5 acres	10 acres	15 acres	20 acres	25 acres	30 acres	35 acres	40 acres	45 acres	50 acres	60 acres	70 acres	80 acres	90 acres	100 acres	150 acres	200 acres	250 acres	300 acres
		Cubic feet per second	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*
Rolling timber	1	2	4	5	6	8	16	23	29	35	39	44	49	55	62	73	83	90	97	103	145	185	216	245
	2	2	3	4	6	8	15	21	26	32	35	40	45	50	56	65	74	80	86	91	127	160	186	210
	3	2	3	4	5	7	13	19	23	28	31	35	39	43	48	56	63	68	73	77	105	130	150	168
Hilly timber	1	3	5	6	8	9	18	27	33	40	45	52	57	64	71	85	96	104	114	122	165	213	252	285
	2	3	4	6.	8	9	17	25	31	36	41	47	52	58	64	75	85	92	102	108	145	184	217	244
	3	3	4	5	7.	8	15	22	27	32	36	41	45	50	55	65	73	79	86	91	120	150	175	195
Rolling pasture	1	5	8	12	15	18	33	47	58	67	77	87	99	110	121	143	164	181	197	208	290	369	433	489
	2	4	8	11	14	17	30	43	53	61	70	79	90	99	109	128	146	160	175	185	251	319	371	419
	3	4	7	10	13	15	27	38	47	54	61	69	78	86	94	110	125	137	148	155	210	260	300	335
Hilly pasture	1	7	13	16	20	24	40	55	67	79	91	102	114	123	142	166	190	210	227	241	334	426	497	572
	2	7	12	15	19	22	37	51	61	72	82	93	104	116	128	148	169	186	202	214	294	369	428	490
	3	6	11	14	17	20	33	45	54	63	72	81	90	100	110	128	145	159	171	180	242	300	345	392
Rolling cultivated	1	8	15	23	29	34	57	77	95	111	128	145	162	182	201	238	271	299	324	344	476	605	720	822
	2	8	14	22	27	32	53	71	87	101	116	132	147	164	181	212	242	265	288	306	419	522	620	703
	3	7	13	20	25	29	47	63	77	89	102	115	128	142	156	183	207	226	244	257	345	425	500	562
Hilly cultivated	1	10	17	27	35	42	70	94	114	134	154	174	193	219	241	285	323	358	389	416	580	727	863	986
	2	10	16	25	33	40	64	86	104	124	139	158	177	198	217	254	288	317	345	369	509	630	742	843
	3	9	15	23	30	36	57	76	92	107	122	138	154	171	187	219	246	271	292	310	420	512	600	675
Terraced rolling cultivated	1	6	9	14	18	21	40	54	68	81	93	107	120	137	155	189	223	264	293	315	465	605	720	831
	2	5	9	13	16	20	36	50	62	73	84	97	109	124	139	168	199	234	260	280	409	522	620	712
	3	5	8	12	15	18	33	44	55	65	74	85	95	107	120	145	170	200	220	235	337	425	500	570

[1] Based on the recommendations of C. E. Ramser.

[2] "Rolling" designates 5- to 10-percent slopes; "hilly," 10- to 30-percent slopes.

[3] Group 1 includes the entire States of Florida and Louisiana, the southern portions of Georgia and Alabama, the southern half of Mississippi, and the southeastern part of Texas. Group 2 includes central Texas, all of Oklahoma except the Panhandle, the eastern half of Kansas, southeastern Nebraska, the southern half of Iowa, western Illinois, all but the southeastern tip of Missouri, all but the northeastern corner of Arkansas, South Carolina, that part of Mississippi, Alabama, and Georgia not included in group 1 (except for the extreme northern parts of these States), the eastern and central portions of North Carolina and Virginia, Delaware, the eastern half of Maryland, New Jersey, and the southern extremes of Connecticut and Rhode Island. Group 3 may be used for all other areas except where local information indicates higher run-off rates.

particular drainage area before it is possible to design structures to control the run-off or even to know what structures can best be used. Run-off rates are generally of more significance than the total amounts of run-off discharged in computing required discharge capacities for control structures. A possible exception would be where control is obtained through run-off retention or absorption, in which case the amount of run-off may become the deciding factor rather than the maximum rates. Terraces, diversion ditches, drainageways, and spillways must have sufficient capacity to carry the run-off resulting from the maximum rainfall intensities likely to occur during the probable life of the control structure. This period is generally from 5 to 10 years for small check dams, terraces, and diversion ditches and from 20 to 50 years for the more expensive soil-saving dams. The maximum rainfall intensity that is likely to occur during a period of 5 years is usually spoken of as having a frequency of 5 years, and similarly for any other number of years. For example, a dam designed with sufficient spillway capacity to handle the run-off resulting from a rainfall intensity that the records show will probably occur only once in 10 years is said to be designed on a 10-year rainfall intensity-frequency.

It is evident that considerable experience is required to estimate run-off from a drainage area. An inexperienced man is apt to be considerably in error in his estimates. Table 1 is included for the convenience and use of those inexperienced in making run-off determinations. Unless an individual is entirely familiar with the procedure of estimating run-off rates it is suggested that he use this table in arriving at run-off values for gully-control structures. Its use will insure reasonably safe design values for even the more adverse conditions that may be encountered in the field. The run-off rates given in table 1 should not be used for the design of large or expensive permanent dams, which are usually designed for a rainfall intensity-frequency exceeding 10 years.

Suppose it is desired to know the probable run-off from a rolling cultivated field comprising about 35 acres, located in southern Iowa. In table 1 find "rolling cultivated." Southern Iowa is in group 2, so follow the line from the "2" opposite "rolling cultivated" across the page to the column headed 35 acres. The figure here is 132. It indicates that the probable rate of run-off on a 10-year frequency from this 35-acre drainage area will be about 132 cubic feet per second. It is important that the drainage areas be properly classified according to location in group 1, 2, or 3, as it can be seen that there is considerable variation in the run-off rates in each of these groups.

It frequently occurs that a drainage area is a composite of pasture, woods, and cultivated land. In order to arrive at the run-off from such an area, the run-off from the several units should be estimated in this way. Suppose a drainage area (located in group 2) consists of 60 acres of land with slopes of between 10 and 30 percent, which is classified as "hilly," 30 acres, or one-half of this drainage area, is in timber, and the remainder is in pasture. From table 1 the run-off from 60 acres of hilly timber is found to be 75 cubic feet per second, one-half of which would be 37½ cubic feet per second. The run-off from 60 acres of hilly pasture would be 148 cubic feet per second, one-half of which would be 74 cubic feet per second. Adding these, the total probable run-off is found to be 111½ cubic feet per second.

It is important to note that the proper figure is computed in this manner and not by adding the run-off from a 30-acre watershed of timber and a 30-acre watershed of pasture.

CONTROLLING RUN-OFF

Applicable methods of handling the run-off to facilitate gully control differ for various types and sizes of gullies and drainage areas. Other important factors that in part determine the best method to be used are soil types and climatic conditions. From the standpoint of economy and practicability, the methods should be considered in the following order:

1. Retention of run-off on the drainage area.
2. Diversion of run-off above the gullied area.
3. Conveyance of the run-off through the gully.

In field practice, local conditions often prohibit the use of certain of these methods, but they should always be given consideration in the order named. No method should be discarded as impractical until thorough investigation has proved it to be so. Frequently the most practical solution will be the use of a combination of the three methods. It should be kept in mind that, wherever practical, vegetation should be reestablished in gullied areas. The methods of controlling run-off are to aid in such establishment and are not to be considered as substitutes that will make unnecessary the use of vegetation on either the drainage area or in the gully.

Whatever the method of run-off control used, it should be carefully planned and executed. Haphazard work will lead to disappointment and may actually aggravate rather than alleviate the conditions being treated. Any work that is done should further the general plan for control of the gullied area.

RETENTION OF RUN-OFF

Keeping the soil and moisture on a gullied field by means of proper land use and approved cropping and tillage practices lessens considerably the amount of run-off to be carried away through the gully and thereby reduces the amount of treatment needed in the gully itself. If these practices still permit so much run-off to enter the gully that vegetation cannot be established there, the use of subsoiling, contour furrows or ridges, listing, level terraces with closed ends, or earth fills to impound water may also be advisable. These erosion controls are not difficult to construct, and they retain considerable moisture for crops. If they can be applied over the entire drainage area of small gullies or even of medium-sized gullies that have small to medium-sized drainage areas on which the soils are absorptive, the slopes moderate, and rainfall low, little or no control may be necessary in the gully itself.

SUBSOILING

On areas having absorptive soils, subsoiling small watersheds above gullies to a depth of 1 to 2 feet has proved effective in reducing the run-off sufficiently to permit satisfactory establishment of a vegetative cover in the gully. Subsoiling requires the use of a special subsoiling machine. Machines of various widths may be used, depending on

the power available. The chisel points are usually spaced on 1- to 2-foot centers, depending on the depth of penetration desired. Subsoiling should be done on the contour and may be either in strips or continuous on the field, depending on the amount of absorption required. It is frequently used in conjunction with contour ridges or absorptive-type terraces. A small subsoiled strip immediately above contour ridges or terraces will open up the soil so that much more run-off can be absorbed.

CONTOUR FURROWS AND LISTING

Contour furrows or ridges are primarily small ditches or ridges constructed across the slope with a plow, lister, or terracing machine (fig. 6). Their storage capacity is dependent on their water cross-

FIGURE 6.—There will be little run-away water from this contour-furrowed field to give gullies a start. The stock pond also retains considerable water.

sectional area and their spacing. Various storage capacities can be obtained by regulating the size and spacing of the furrows.

The storage capacity for contour furrows or ridges with various spacings and water cross-sectional areas is given in table 2. If, for example, it is desired to store 2.5 inches of run-off in contour furrows having a water cross section of 1.25 square feet, the furrows should be spaced about 6 feet apart. The storage capacity of the furrows given in table 2 does not include the water that seeps into the soil. The ends of the furrows or ridges are usually turned uphill and the channels blocked at occasional intervals so that, in the event of a break, all the water cannot drain from the furrow and thus encourage gullying. Lister furrows (fig. 7) have been used extensively on cultivated land in the Great Plains to keep rainfall on the fields. On gullied watersheds they can be used to keep water out of the gullies.

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TABLE 2.—*Horizontal spacing of contour furrows or ridges*

Storage capacity (inches of run-off)	Distance between furrows where the water cross-sectional area [1] is— 0.50 square foot	1 square foot	1.50 square feet	2 square feet	2.50 square feet	3 square feet	3.50 square feet	4 square feet	4.50 square feet	5 square feet	5.50 square feet	6 square feet	6.50 square feet	7 square feet	7.50 square feet	8 square feet
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
0.25	24.0	48.0	72.0	96.0	120.0	144.0	168.0	192.0	216.0	240.0	264.0	283.0	312.0	336.0	360.0	384.0
0.50	12.0	24.0	36.0	48.0	60.0	72.0	84.0	96.0	103.0	120.0	132.0	144.0	156.0	168.0	180.0	192.0
0.75	8.0	16.0	24.0	32.0	40.0	48.0	56.0	64.0	72.0	80.0	88.0	96.0	104.0	112.0	120.0	123.0
1	6.0	12.0	18.0	24.0	30.0	36.0	42.0	48.0	54.0	60.0	66.0	72.0	78.0	84.0	90.0	96.0
1.25	4.8	9.6	14.4	19.2	24.0	28.8	33.6	38.4	43.2	48.0	52.8	57.6	62.4	67.2	72.0	76.8
1.50	4.0	8.0	12.0	16.0	20.0	24.0	23.0	32.0	36.0	40.0	44.0	48.0	52.0	56.0	60.0	64.0
1.75	3.4	6.9	10.3	13.7	17.1	20.6	24.0	27.4	30.9	34.3	37.7	41.1	44.6	48.0	51.4	54.9
2	3.0	6.0	9.0	12.0	15.0	18.0	21.0	24.0	27.0	30.0	33.0	36.0	39.0	42.0	45.0	48.0
2.25	2.7	5.3	8.0	10.7	13.3	16.0	18.7	21.3	24.0	26.7	29.3	32.0	34.7	37.3	40.0	42.7
2.50	2.4	4.8	7.2	9.6	12.0	14.4	16.8	19.2	21.6	24.0	26.4	28.8	31.2	33.6	36.0	38.4
2.75	2.2	4.4	6.5	8.7	10.9	13.1	15.3	17.4	19.6	21.8	24.0	26.2	28.3	30.5	32.7	34.9
3	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0	22.0	24.0	26.0	28.0	30.0	32.0
3.50	1.7	3.4	5.1	6.9	8.6	10.3	12.0	13.7	15.4	17.1	18.0	18.9	19.7	20.6	21.4	22.3
4	1.5	3.0	4.5	6.0	7.5	9.0	10.5	12.0	13.5	15.0	16.5	18.0	19.5	21.0	22.5	24.0
4.50	1.3	2.7	4.0	5.3	6.7	8.0	9.3	10.7	12.0	13.3	14.7	16.0	17.3	18.7	20.0	21.3
5	1.2	2.4	3.6	4.8	6.0	7.2	8.4	9.6	10.8	12.0	13.2	14.4	15.6	16.8	18.0	19.2
5.50	1.1	2.2	3.3	4.4	5.5	6.6	7.6	8.7	9.8	10.9	12.0	13.1	14.2	15.3	16.4	17.5
6	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0
6.50	.9	1.8	2.8	3.7	4.6	5.5	6.5	7.4	8.3	9.2	10.1	11.1	12.0	12.9	13.8	14.8
7	.9	1.7	2.6	3.4	4.3	5.1	6.0	6.9	7.7	8.6	9.4	10.3	11.1	12.0	12.9	13.7

[1] For water cross-sectional areas in excess of 8 square feet the required spacings can readily be determined by multiplication. Example: For a water cross-sectional area of 15 square feet the spacing would be 3 times that required for a cross section of 5 square feet; it would be about 90 feet if 2 inches of run-off is to be retained.

FIGURE 7.—These lister furrows are holding water on the field. Keeping excess water out of gullies makes it much easier to get vegetation started in them.

ABSORPTIVE-TYPE TERRACES

Absorptive-type terraces are constructed larger than contour ridges, and they provide more storage capacity, are spaced farther apart, and can be farmed over if necessary. Their ends can be left partly or completely open, depending on the necessity for some drainage as a factor of safety against overtopping. Where these terraces are to be depended upon to retain all of the excess rainfall, they should be used on only moderate land slopes (generally less than 2 percent) and pervious soil types. It will usually be necessary to provide storage for at least 2 to 4 inches of run-off in areas of low rainfall, and a capacity of as much as 6 to 7 inches may be necessary in areas with high rainfall. The expense and difficulty of providing a storage capacity of 6 to 7 inches usually makes the use of adequate retention measures impractical in areas where rainfall is high. Furthermore, if crops are to be grown on a field containing these terraces, the retention of an excessive amount of water may damage the crops before the water can be absorbed by the soil.

EARTH FILLS

On cultivated areas with absorptive soils, small- or medium-sized gullies with small watersheds can sometimes be reclaimed by placing a series of earth fills across the gullies. Their spacing is dependent on the slope of the gullies. The use of this method is limited to areas where sufficient storage capacity can be provided above the earth fills to retain the major portion of the run-off that is commonly discharged from the drainage area. The earth fills are extended above the ground level, and short diversion ditches or spur terraces are sometimes used to lead overflow away from the ends of the fills in order to prevent damage by erosion. Where a series of earth fills are used and the overflow is diverted from alternate sides, somewhat of a sirup-pan retention is effected. The diverted water is finally either impounded in the gully or absorbed by the soil. The use of this or similar methods requires considerable attention. As the storage capacity of the small reservoirs is gradually reduced by silt

deposition, the amount of overflow will increase and may start erosion unless sufficient plant cover has become established to afford protection.

On fields where the measures discussed in this section do not provide sufficient storage capacity to retain the run-off and keep it out of the gullies, drainage-type terraces or diversion ditches may also have to be used to divert part of the run-off.

DIVERSION OF RUN-OFF

Where necessary and practical, run-off should be diverted from a gully head before control measures are attempted within the gully. This principle generally applies to gullies of all sizes except those having so small a drainage area that the run-off is negligible, as for example, a gully with a drainage area of less than an acre. In using either terraces or diversion ditches careful consideration should be given to the disposal of the diverted water. If safe disposal cannot be provided, the water should not be diverted. The disposal of concentrated run-off over unprotected areas may cause gullying.

FIGURE 8.—The terraces on this field run across the gully, intercepting the flow of water down the gully. The fills across the gully must be carefully made so that the terraces will prevent further gullying and reclaim the gullied area.

Terraces are very effective in the control of small gullies on cultivated fields or even medium-sized gullies that are not too deep to be crossed with the terracers (fig. 8). Terraces placed above a gully too deep to be terraced across will divert headwaters from the gully, which may then be treated further if necessary. Terrace construction may be difficult and somewhat expensive on gullied areas, but despite this it is frequently the most satisfactory control measure for terraceable slopes, and particularly where numerous parallel gullies are encountered on slopes that are difficult to vegetate. Figure 9 shows a previously gullied field that has been almost completely reclaimed by terracing. The terraces were constructed across the gullies. This diverted the run-off at points where the terraces crossed the gullies and allowed the gullies gradually to fill with silt.

If the slopes above a gully are too steep to terrace or if the drainage

area is pasture or woodland, diversion ditches (fig. 10) may be used to keep run-off out of the gully. Diversion ditches are particularly adapted to areas already covered with trees or grass because ditches below these areas are not so likely to receive silt loads from the drain-

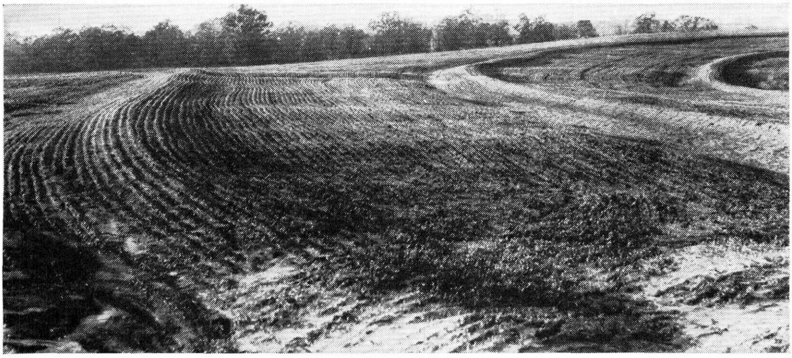

FIGURE 9.—Before this field was terraced and contour-tilled it was gullying extensively. The scars of some of these gullies are still visible in the immediate background.

age area. Diversion ditches are not recommended immediately below cultivated fields not fully protected from sheet erosion unless a permanent filter strip of close-growing vegetation is placed above the ditch to catch the silt carried in the run-off from the fields. This filter strip should have a minimum width of 50 feet and adequate cover to

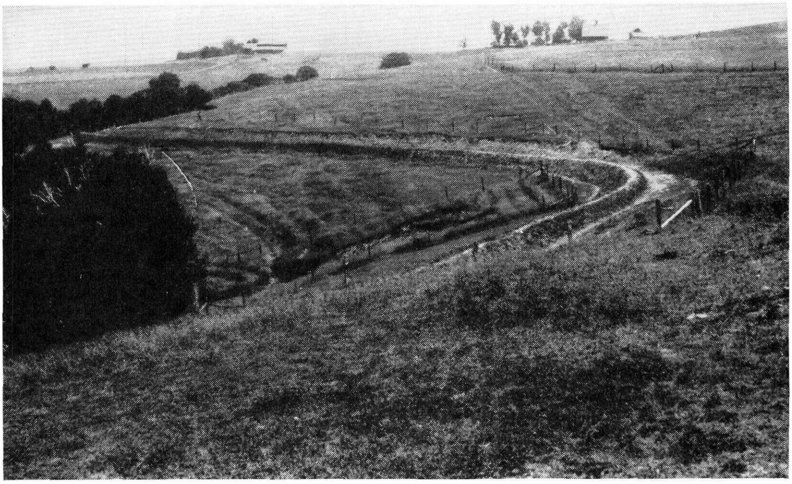

FIGURE 10.—The water is intercepted by a diversion ditch above the gully and carried to a disposal point so slowly that little erosion occurs. The fence keeps out livestock.

filter out and retain the silt in the run-off. This will reduce silt deposition in the ditch channel and eliminate the need for much subsequent maintenance.

Diversion ditches should be made large enough to carry all the run-off that will be discharged from the contributing drainage area during

periods of maximum run-off from rains within the design frequency selected (p. 13). This run-off should be conveyed through the ditch at nonerosive velocities. The velocity of run-off in the ditch can be controlled by regulating the grade and shape of the water channel. Wide, shallow ditches on mild grades produce lower velocities than narrow, deep ditches on steep grades. In channels maintained by a permanent plant cover a higher discharge velocity is recommended than in raw channels. The higher velocity is essential to prevent undue silting.

For shallow earth channels not having a cover of vegetation the maximum grade should seldom exceed 12 inches per hundred feet of length in order to prevent scouring velocities. Where a permanent plant cover is to be maintained in the channel, grades as high as 2 to 3 percent or more may be used. Serious scouring will likely occur with these steeper grades if the vegetative protection is ever destroyed, and they should be used only where adequate vegetative protection can be depended on during all periods that produce run-off.

The terrace-type diversion ditch is extensively used for ordinary locations where the watershed area is about 7 or 8 acres (fig. 11). This type of diversion ditch is constructed from both the upper and lower sides on relatively flat slopes. On steeper slopes (of above 3 or 4 percent) construction is generally from the upper side only. There are, of course, many variations from the indicated cross sections because of the local variations in soil types, available construction equipment, rainfall, and slopes. The ditch should be constructed according to the required capacity. The settled depth of the water channel should seldom be less than 18 inches, and a minimum water cross-sectional area of 7.5 square feet is suggested for drainage areas up to 5 or 6 acres. Drainage areas up to 10 acres require a channel depth of 24 inches and a minimum cross section of 12 square feet.

For larger drainage areas, cross section *C*, shown in figure 11, is suggested, especially on the steeper slopes. It is recommended that the services of an individual with experience in hydraulic design be secured to compute

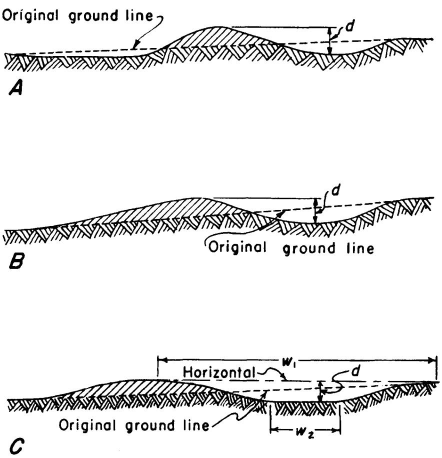

FIGURE 11.—Diversion-ditch cross sections: *A*, Terrace-type diversion ditch on relatively flat slopes. Construction from both sides. Minimum value of *d* about 18 inches. *B*, Terrace-type diversion ditch on steeper slopes. Construction generally from the upper side only. Minimum value of *d* about 18 inches. *C*, This type of diversion ditch is suggested for drainage areas exceeding 10 acres, especially on the steeper slopes. *d* should be a minimum of 22 inches. Side slopes should be at least 4:1 where land slopes permit. The approximate water cross-sectional area of the ditch is $\frac{(w_1+w_2)}{2}\,d$.

channel capacities and dimensions for these larger watersheds. A poorly designed diversion ditch is more apt to induce than to prevent gullying.

The diversion ditch should be set back from the head of the gully a minimum distance of three times the height of the gully overfall. Low points in the ridge and high points in the channel should be corrected before the ditch is put to use. If well-protected natural outlet locations can be found, no special outlet revegetation or construction will be necessary. If none are available it is necessary to take certain precautions to spread the concentrated run-off on vegetated areas. Natural outlets should always have preference if they are satisfactory. It is sometimes possible to discharge the diversion ditch into an outlet or drainageway already established for a terrace system. If this is done, provision should be made for the additional water to be carried by the outlet channel.

Sometimes it is necessary to establish sodded outlet areas before constructing the diversion ditch. Contour furrows have also been used to spread and absorb water from diversion ditches where soils are pervious and the amount of run-off is not very large. The furrows should preferably be established at least a year before the water is diverted into them, so that the furrows as well as the intervening areas may become vegetated before additional run-off is discharged onto them.

CONVEYING RUN-OFF THROUGH GULLIES

If it is not possible to keep water out of gullies by retaining it all on the watershed or diverting it from the gullies, the run-off must be conveyed through the gullies. To do this and to check erosion in those gullies at the same time is possible if vegetation can be established in the gullies or mechanical structures built at critical points to supplement vegetation or to give complete control.

It is emphasized, however, that where a gully is located in a natural drainageway that is to form part of the disposal system for surface run-off, it becomes necessary to convey run-off through the gully. Any erosion control applied in the gully must not reduce the capacity of the drainageway below that required to carry the run-off discharged into it.

It is usually much more difficult to establish adequate vegetation in a gully through which run-off must be conveyed during the period of establishment than in one from which run-off can be diverted. Erodible portions of a gully through which water is conducted must usually be protected by transplanting sod, by the use of specially anchored mulches, or by the use of mechanical structures. The mechanical structures need be only temporary if the plant cover, once established, can provide sufficient protection.

If mechanical measures will ultimately be required for satisfactory control, permanent structures, such as masonry check dams, flumes, or earth dams, supplemented by vegetation, should be provided to convey the run-off over critical portions of the gully. Detailed information on the use of vegetation and mechanical structures in gullies is given in the following sections of this bulletin.

VEGETATION

The methods of preventing gullies that have been recommended, as well as the control measures described on pages 28 to 57, are

for the purpose of reducing or controlling run-off so as to make it easier to establish vegetation. The objective of gully control is, in fact, the establishment of an erosion-resistant cover of plants that not only stabilize the gullies but also produce a usable crop, and hence a supplementary income. Just what kind of plants are to be

FIGURE 12.—*A*, This picture was taken soon after the gullied area had been fenced and planted to black locust trees. Very little bank sloping was done preparatory to planting. *B*, The same area 2 years later. The raw gully banks have been almost completely covered with vegetation.

used and how they are planted will, of course, vary according to locality.

In any part of the country, gullied areas are usually the most difficult places on which to try to grow plants. The topsoil is gone; the subsoil is poor or is gone; and the layers finally exposed in the gully may be hardpan or even rock. The revegetation of such places will be difficult. Yet, if the run-off water can be diverted from its old path through the gully, if the soil is given a little preparation,

and if the area is temporarily protected from trampling by livestock, a plant cover can be established (fig. 12).

Bank sloping is expensive as a means of preparing a gullied site for planting. It can usually be justified only if the banks of the gully are so steep that vegetation cannot otherwise be established or if it is desired to partly fill a small gully to facilitate tillage operations. As little bank sloping as possible should be done, for under ordinary conditions the banks will gradually assume a stable slope. The necessary sloping can be done by hand labor, by machinery, or by blasting.

Sloping by hand labor is slow and may be expensive if much of it is to be done. A more practical method is to use a light walking plow and team. Considerable skill is necessary to maneuver the plow and team properly, but with a little practice it is soon possible to "plow down" a gully bank. For the first few rounds it may be necessary to hitch a chain to the plow if it is difficult to bring the team near the edge of the gully bank. Fine brush, straw, manure, or similar material may be used in filling a gully if sufficient loosened dirt is used to anchor and cover it.

On large gullies or in hard soils it may be necessary to use a bulldozer or explosives. Either may prove costly, and they should not be used indiscriminately. On large jobs the bulldozer will usually move soil at a lower cost per unit volume, but it requires considerable overhead investment and equipment that is not available on the ordinary farm.

It should be kept in mind that in site preparation bank sloping is necessary only to the extent of securing ground slopes and a surface condition satisfactory for planting or seeding. Usually planting and seeding can be done and a satisfactory growth produced without any extensive bank sloping. The ground should be left in a roughened condition for either planting or seeding.

NATURAL REVEGETATION

Any gully, no matter how large, and regardless of its condition, will usually be reclothed with vegetation, provided it is properly protected and is in a locality where vegetation will grow. If the water that causes the gully is diverted and livestock, fire, or any other cause of disturbance kept from the gullied area, plants begin to come in. At first they come very slowly because it is hard for them to get a foothold. Later, when the pioneer plants have improved the soil somewhat, other plants appear. The whole natural process may take many years in the drier parts of the country, but where there is more moisture, the process is more rapid.

Plants will always come in naturally on protected areas, but on gullied land there are several things that slow down the final healing of the erosion scar. One is the continued loss of soil caused by freezing, thawing, and washing (fig. 2, *C*). This loss cannot always be stopped, but it can often be reduced by the use of a mulch of boughs, straw, or leaves, which also assists in catching and holding plant seeds. Another thing is the steepness of some gully banks. Until the steep sides cave in and reach a gentler slope (about a 1:1 slope), it is difficult for plants to root themselves. Unless large gullies with steep banks are plowed in, pushed in with a bulldozer, or dynamited, it may take many years for them to become stabilized.

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In spite of conditions such as these, hardy, thrifty plants capable of surviving in gullied areas will generally appear naturally. So-called "weeds" will usually come first. They prepare the way for other plants, which always follow them in a year or two. Given sufficient time, this natural process will eventually reclothe the gully with the predominant vegetation of the region, whether that be trees, brush, or grass. Frequently this opportunity to obtain a cheap protective covering is overlooked and unnecessary expenditures are made for structures or plantings. Many previously active gullies have been completely stabilized by a natural growth of vegetation that sprang up after the land was abandoned and livestock excluded (fig. 13). Natural revegetation, however, may be a lengthy process.

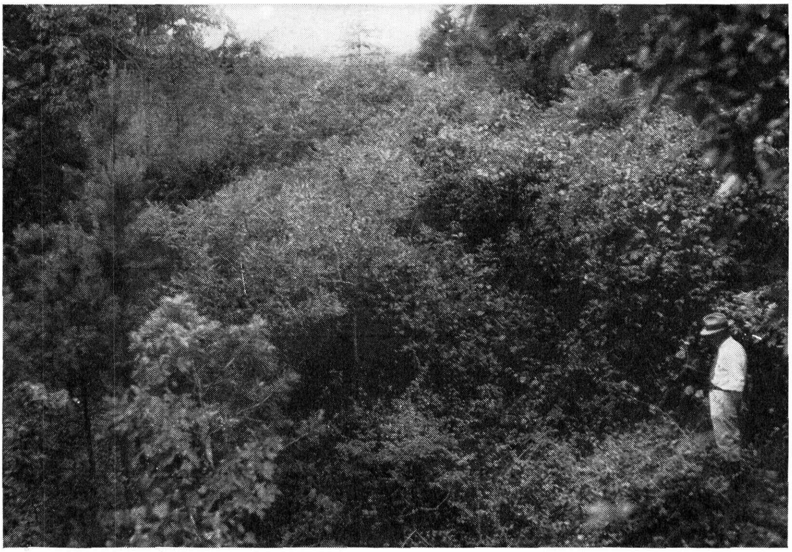

FIGURE 13.—Plants that come in naturally are usually very hardy and thrifty. They have completely stabilized this gully, which originally was about 25 feet deep.

Where natural growth does not appear to be able to cope with existing erosion or where certain plant species of economic value are desired, it may be necessary to consider ways and means of establishing vegetation artificially.

PLANTING AND SEEDING FOR REVEGETATION

CHOICE OF PLANTS

So far as erosion control alone is concerned, it makes little difference whether trees, shrubs, vines, or grasses are used in a gullied area. Any of these, if well-established, provides good protection for soil. Consequently, the kind of vegetation to use is best chosen on a basis of what the planted area will be used for when it is stabilized.

A stabilized gully can be used as a woodland area, as a wildlife habitat, as a drainageway for water, or as pasture land or hay land. It should not be cultivated, however, nor should it be burned, brushed, or used in a way that will promote erosion. If it is to be used as a drainageway, grass is ordinarily the primary cover (fig. 14). Grass

sod can carry more water safely and at higher speeds than can woody plants. A sodded drainageway can be crossed with farm machinery, whereas one with a woody cover cannot. Grassed drainageways produce good yields of hay in some sections. If they are utilized as pasture, grazing should be regulated. It should not be forgotten, however, that good grass growth demands a well-prepared seedbed and reasonably fertile soil, a condition rarely present in gullies.

FIGURE 14.—A growth of bluegrass and black walnut trees protects this gully. The gully is used to carry surface run-off from an adjacent field.

In certain regions trees and shrubs are easier to establish in gullied areas than grasses, but they should not be used in drainageways unless the amount of water flowing in the channel is relatively small (fig. 15). Trees on a gullied area will produce a crop of fence posts or rough timber for general use about the farm. Shrubs are used particularly to attract wildlife, especially insect-eating birds, if the gully is near cropland, although many trees and grasses are also valuable to wildlife.

Where severely eroded and gullied areas must be retired from crop land or pasture land, woody plants are usually used to help stabilize

FIGURE 15.—A 10-year growth of black locust trees has completely stabilized this gully, which originally was about 17 feet deep. The gully carries very little water.

them, and the areas are then ordinarily reclassed as woodland and wildlife areas.

TREES, SHRUBS, AND VINES

Preparation of area.—Before gullied areas are planted, they should be fenced from livestock unless they are in a field in which livestock does not run. Trampling and grazing by domestic animals in these critically eroding areas will prevent vegetation from forming a good cover, which is essential in preventing washing.

The area to be fenced or otherwise protected should be larger than the width of the gully. For example, if a gully is about 10 feet deep, the distance from the fence to the nearest edge of the gully should be 20 to 25 feet. It is better to allow an even greater distance at the gully head because at the head the erosion hazard is greatest.

Selection and planting of species.—The first choice of trees, shrubs, and vines for gullies should be plants that are native to the locality and grow on similar sites. These plants are already acclimated and thus have the best chance of survival under the harsh growing conditions in gullies. If useful native plants are unsatisfactory, second choice would fall on plants introduced from other areas or countries.

There are a number of native trees, shrubs, and vines that have proved satisfactory in controlling gullies. Among trees may be listed black locust (*Robinia pseudoacacia*), catalpa (*Catalpa* sp.), Chinese elm (*Ulmus parvifolia*), cottonwood (*Populus* sp.), green ash (*Fraxinus lanceolata*), hackberry (*Celtis occidentalis*), honeylocust (*Gleditsia triacanthos*), mulberry (*Morus* sp.), northern red oak (*Quercus borealis*), Osage-orange (*Maclura pomifera*), pine (*Pinus* sp., in general), and willow (*Salix* sp.). Shrubs and vines that have proved effective in gully planting done by the Soil Conservation Service so far include several shrub dogwoods and osiers (*Cornus asperifolia*, *C. stolonifera*,

C. paniculata), viburnums (*V. lentago*, *V. dentatum*, and *V. trilobum*), chokecherry (*Prunus virginiana* and *P. demissa*), Russian-olive (*Elaeagnus angustifolia*), wild plum (*P. americana*), skunkbush (*Rhus trilobata*, paloblanco (*Forestiera neomexicana*), sugar sumac (*Rhus ovata*), and coralberry (*Symphoricarpos orbiculatus*), kudzu (*Pueraria thunbergiana*), and Japanese honeysuckle (*Lonicera japonica*). It should be mentioned that honeysuckle is of very little value to wildlife.

This list could easily be supplemented by other species, since there are many others that have been used successfully. Additional selections may be made from plants recommended by the local county agent.

In using woody plants it is well to remember that solid plantations of one kind are undesirable because they favor the spread of any insect or disease that may attack them. Neither do they encourage wildlife as much as mixed stands do. In mixtures of shrubs and trees, the shrubs should be placed on the less favorable sites, the trees on the better ones. Also, the whole gullied-area plantation may well be planted around its outer edge with two or more rows of shrubs of particular value to wildlife. These outer-edge rows also serve to protect the tree plantings within.

Vines are ordinarily not planted with trees and shrubs because they prevent the best growth of these woody plants by clambering over them. In some parts of the country, however, vines may be used satisfactorily in a gullied area (fig. 16).

The spacing of plants will depend on local conditions, but 6 feet apart in each direction is the maximum spacing ordinarily recommended for erosion control. Spacings of 3 by 3 feet and 4 by 4 feet are better for shrubs in the gully. On the edge rows along the banks 6 by 6 feet is satisfactory. No plants should be placed on very steep banks in steps cut in the bank. Nor should they be planted under overhangs or too close to edges of banks that will eventually cave in.

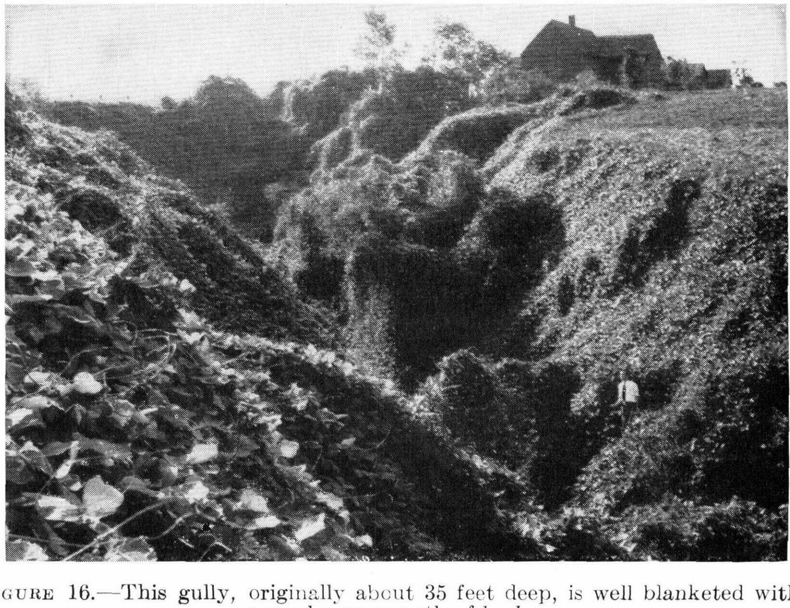

FIGURE 16.—This gully, originally about 35 feet deep, is well blanketed with a second-year growth of kudzu.

It is important to get good planting stock to transplant. Nursery-grown stock has proved much better than wildings in most parts of the country. Because the gullied areas have such poor soil, the stronger and more thrifty the planting stock the greater the chance of establishing the plants the first time. Suitable nursery stock can ordinarily be obtained from local nurserymen or from State nurseries.

Just as with other crops, the use of fertilizer with trees or shrubs placed in gullies assures increased survival and growth.

SHRUB CHECKS

In small or medium-sized gullies with small drainage areas it is frequently possible to construct checks consisting of shrubs placed across the flow line of the gully (fig. 17). The shrubs are placed 4

FIGURE 17.—Shrub checks in a small gully. Note the close spacing of the checks.

to 5 inches apart in shallow trenches and are sometimes protected by rows of stakes. The stakes are placed about 1 foot down the channel from the shrubs so that the plants will benefit from silt collected by the stakes. The shrub checks reduce water velocities in the gully channel and induce silting, which gives other vegetation a chance to become established. Shrub checks should be closely spaced if they are to be effective. They should be used only in gullies that have a mild grade.

WILLOW CHECKS

Another type of check frequently used in gullies with small drainage areas and of moderate slope is constructed of willows. Willows are used only in locations where the soil is naturally moist throughout the year. Cuttings are made from green willow trees and set in rows across the gully at intervals of about 1 foot. Sometimes several rows are placed close together. These cuttings take root and form a living check across the gully.

Further information on the use and planting of trees, shrubs, and vines in the control of gullies is given in various State publications and in Farmers' Bulletin 1788, Wildlife Conservation Through Erosion Control in the Piedmont.

GRASSES AND GRASS-LEGUME MIXTURES

Grass covers are usually preferable for scattered gullies in good pasture or in cultivated fields where the preparation of an adequate seedbed is not difficult.

Grass covers may be produced by seeding or by transplanting sod. The use of manure or commercial fertilizer is usually required for good growth. Wherever applicable, seeding is the cheaper method. Mulching the seeded areas with light covers of straw, cane, or fine brush conserves moisture and is beneficial in assisting grass seed to become established on these areas.

In seeding, it is generally advisable to use a mixture of adapted grasses and legumes to insure complete stands and early stabilization of the gully. As the less adapted species thin out, the more aggressive ones will spread to replace them and thus perpetuate a complete ground cover.

Among the grasses and legumes that have stabilized gullies, Kentucky and Canada bluegrass, redtop, Bermuda grass, clovers, annual and perennial lespedezas, Kikuyu grass, wheatgrasses, bromegrass, and Napier grass have been commonly used in areas where they are adapted. Many other plants may be used for the purpose, and the local county agent should be consulted before a selection is made.

Small or medium-sized gullies to be seeded in cultivated fields should be plowed in or otherwise partly filled in order to convert them into broad channels, which permit the water to spread. The spreading of water reduces its cutting power. After the channel has been properly shaped, a firm seedbed should be prepared and fertilizers applied if they are needed. Seeding may be done by broadcasting or drilling. If the seed is broadcast, the ground should be harrowed lightly afterwards to cover the seed and then firmed by packing. In the semiarid sections, drilling is much preferred to broadcasting because it places the seed in moist soil and thereby insures more rapid and uniform germination. If the drill is used, it is advisable to run it in a zigzag pattern, crossing the gully as often as conveniently possible. This will keep the drill rows from running with the gully and will reduce the danger of rilling between the rows. After the ground has been drilled, it should be firmed with a packer driven in a zigzag line. In constructing drainageways of this kind it is poor economy to attempt to confine the channel to too small an area. The grasses should be seeded well out over the embankment, and it is desirable to leave the edge of the seeding irregular to prevent the formation of new gullies along the sides.

Grass and leguminous plants are very tender in the seedling stages, and every precaution must be taken to keep run-off water out of the newly seeded drainageway until the plants are well established. In addition to any permanent diversions that may have been installed, it is sometimes advisable to construct a temporary dike along the sides of the drainageway to exclude run-off until a good growth has been obtained. In the larger drainageways where such a dike would

not be practical and where it is impossible to exclude all run-off in any other way, it is often advisable to plant a quick-growing annual crop to stabilize the drainageway before the grasses are seeded. Small grains, Sudan grass, lespedezas, and similar cover may be seeded in the spring to hold the soil and produce a residue in which to seed the grasses the following fall. Nurse crops may also be seeded with the grasses to give quick protection, but care must be taken not to seed the nurse crop so thick that it will compete with the grasses for moisture or smother the small grass and leguminous plants.

SODDING

If an immediate grass cover is required and suitable sod is available, it may be necessary to transplant sod. Sodding is generally too costly for extensive use over large gullied areas. Sod is needed, however, on critical sections at the gully head or at points along the bank or bottom where protection against waterfall erosion is necessary. It is also frequently used in connection with permanent structures. Grass covers can usually be established through sodding on areas exposed to run-off where it would be impractical to secure a cover by seeding. Where the amount of run-off is not too large, and good sod is available, it can be used as a substitute for the more costly masonry and concrete materials. Sod flumes, sod check dams, and sod spillways have all functioned satisfactorily when properly constructed and applied.

TRANSPLANTING SOD

There are three general methods of transplanting sod: Solid sodding, broadcast sodding, and spot or strip sodding. Solid sodding consists of cutting the sod in strips and transplanting it as a continuous cover over the area to be sodded. The sod is usually cut in strips about 1 foot wide, 8 to 10 feet long, and 1½ to 2½ inches thick. The amount of time and labor required to cut the sod can be materially reduced by the use of special horse- or tractor-drawn sod cutters. When transplanted, the strips are continuous and are usually laid on the contour or at approximately right angles to the direction of the water flow. It is desirable to staple the sod down or cover it with wire mesh if there is danger of heavy run-off before the sod can establish itself. Care must be exercised in cutting, placing, and tamping the sod. Solid sodding is the most costly type of sodding, but it provides a cover that is capable of conveying considerable run-off almost immediately after it is placed.

Broadcast sodding requires less labor and time, particularly if suitable equipment is available. The area from which the sod is to be taken is disked until the sod is well cut up and mixed with the topsoil. This mixture of grass roots and topsoil is then collected and transported by scrapers or spreaders and spread in layers 2 to 3 inches thick over the area to be sodded. After it is placed, the area should be disked so as to work the sod into the soil on the new location. The fertile topsoil transplanted with the sod roots promotes a vigorous growth. Unfortunately broadcast sodding can be used in transplanting only grasses that spread by rootstocks, and it does not provide a surface cover capable of conveying run-off so soon as solid sodding. It has been used with good results in transplanting Bermuda grass. This method is relatively inexpensive.

Strip sodding and spot sodding are commonly used in transplanting sod. In strip sodding, the strips of sod are ordinarily laid in trenches of the same dimensions as the sod. Sometimes they are laid at regular intervals across the slope to be sodded, and the intervening areas are filled with topsoil and seeded. In either arrangement the top of the sod strip should be flush with the top of the adjacent ground surface.

Spot sodding consists of transplanting small clumps of grass, rootstocks, or stolons at random over the area to be sodded. These are usually placed in small holes.

Strip sodding and spot sodding give quicker coverage with less sod than solid sodding, but they require a longer time to provide complete protection. They give the most satisfactory results with grasses that spread rapidly by stolons or rootstocks and when used as a means of establishing grass cover on gully bottoms or sides not exposed to excessive run-off.

Sod should be obtained from areas where its removal will not cause serious erosion, or it should be removed in such a manner as to minimize later erosion damage. On sloping land it should be removed only in alternate strips at right angles to the land slopes. Leaving undisturbed contour strips at intervals will usually give sufficient protection to prevent harmful washing until the bare areas are revegetated. For transplanted sod the need and value of liberal applications of farm manure or commercial fertilizer should not be overlooked. The ultimate success of any sodding is dependent on a vigorous growth. If the plant food necessary to assure good growth is not provided on infertile soils, all control efforts may be wasted. The usual procedure is to apply the fertilizer over the area to be sodded before the sod is laid.

SOD FLUMES

Sod flumes may be successfully used to control overfalls in gullies with heads less than 10 feet and drainage areas less than 25 acres. Suitable sod must, of course, be available. In areas of good Bermuda grass or Kentucky bluegrass, sod flumes have been successfully used on larger watersheds in gullies that have low overfalls. A flume merely serves the purpose of preventing further waterfall erosion by providing a protected surface over which the run-off may flow into the gully (fig. 18). It is not intended to fill a gully or to stabilize the gully channel or sides below the flume.

The overfall to be sodded must be cut back to a slope flat enough to make possible the establishment and maintenance of a permanent plant cover. The allowable slope will depend on the soil type, size of watershed, height of the overfall, and the quality and type of sod used. Generally a 4:1 slope should be about the steepest. To avoid destructive velocities through the flume it should be wide in proportion to its depth and should have sufficient cross-sectional area to carry the expected run-off at nonerosive velocities. A width of at least 15 inches per acre of watershed is desirable, and the maximum depth of flow expected over the flume should seldom exceed 12 inches.

Unless the anticipated run-off is small, solid sodding is usually necessary for sod flumes. It is important that the gully channel below the flume be on a stable grade. If it is not, overfalls may develop below the flume and undermine the sod. On small watersheds that

have erosion-resistant soils, an unprotected gully channel may be reasonably safe for grades of as much as 1½ percent. Channels protected by vegetation can generally withstand considerably higher grades. On the more erodible soil types and larger watersheds unprotected channel beds should usually have a fall of less than 1 foot per hundred feet of length. Unstable grades may be reduced by mechanical measures if it is impracticable to provide the necessary protection by vegetation.

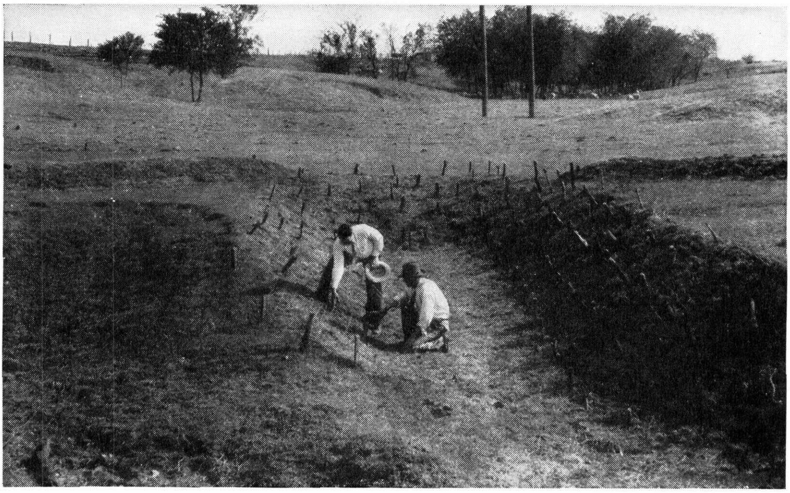

FIGURE 18.—A gully head controlled with a sod flume. The transplanted sod has been staked and wired down so the grass roots will have an opportunity to catch. Note the earth lead-in dikes at the top of the ramp.

SOD CHECKS

Sod checks are frequently used to stabilize gully channels until the intervening areas become vegetated. The several types are merely variations that are made necessary by existing gully conditions and required protection. Two of the more important are the sod strip and the sodded earth fill.

The sod-strip check is best adapted to small gullies (fig. 19) that have small- to medium-sized watersheds and relatively flat channel grades. The strips are laid across the gully channel so that each strip when set will be flush with or slightly below the bed of the gully. The strip should have a minimum width of 12 inches and should extend up the gully sides at least 6 inches above expected high-water crests. (See table 1 for expected run-off.) The spacing of the strips will depend on the spreading characteristics of the sod, the drainage area, and the grade of the gully. Spacings of 5 to 7 feet are commonly used. Where it is difficult to establish vegetation on gully sides, contour sod strips may sometimes be used to advantage.

SODDED EARTH FILLS

Low, sodded earth fills (fig. 20) can often be advantageously used as a substitute for ordinary brush or wire check dams in stabilizing

gully channels. Where suitable sod is available they can be constructed at less expense; and they have an additional advantage because of the fact that by their use vegetation is immediately established at intervals along the gully. They have been successfully used

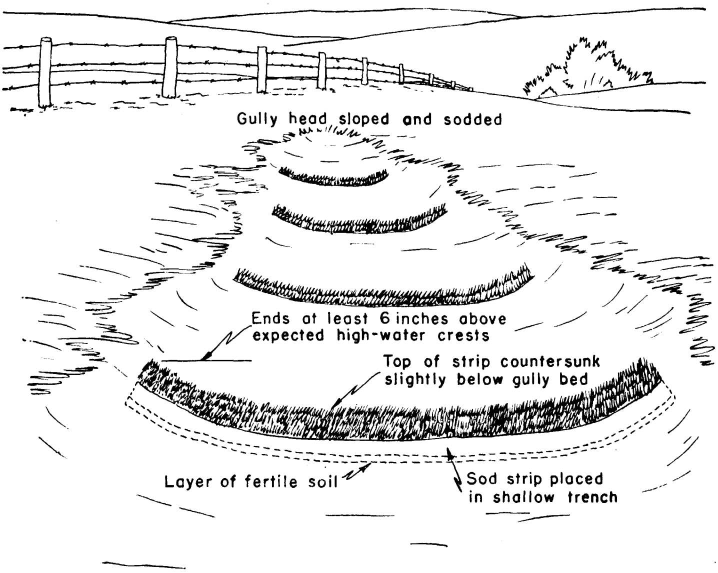

FIGURE 19.—A series of sod-strip checks in a small gully. These checks cannot be used in gullies with steep grades.

in small- to medium-sized gullies with drainage areas of less than 25 acres. The earth fills should be located at strategic points or at regular intervals along the gully, as is necessitated by existing conditions. Frequently these fills are spaced so that the top of each will be as high as the base of the next one above. Side slopes steeper than 3:1 on the upstream side and 4:1 on the downstream face should seldom be used. The fill should be well tamped, and heights in excess of 18 inches should be avoided because of the overfalls created. An average height of 10 or 12 inches is commonly used. The top of the fill should be low in the center and should gradually curve upward to meet the gully sides and provide the necessary spillway capacity. The fill should be solid-sodded on the top and on the downstream face, and it should be carried up the gully sides to a height of 6 to 12 inches above maximum water crest expected over the structure.

STRUCTURES

Structures are used in gullies to facilitate the establishment of vegetation or to provide permanent protection at points that cannot be adequately protected in any other way. They are usually used only in gullies through which run-off must be conveyed. If the run-off that must be conveyed through gullies is not in excess of the amount that can be handled by well-established vegetation, temporary mechanical

structures may be used in the gullies until the vegetation becomes established. Such material as brush, poles, wire, and loose rock are usually used for constructing temporary check dams. If the run-off is of sufficient volume to make ultimate control by vegetation impracticable, permanent mechanical control measures will have to be used. These structures, built to give permanent reinforcement to vegetation, should be made of durable materials; reinforced concrete, masonry, metal, or earth. They should be used only where less expensive means

FIGURE 20.—Sodded earth fills in a small gully. The fills are solid sodded and closely spaced. Their average height is about 10 inches.

are impracticable and should be supplemented by vegetation wherever possible.

The proper use of structures in gullies requires good judgment in determining the need for them and the extent of their use. It is just as great a mistake to attempt to control a gully without structural assistance in areas where structures would ultimately provide the most satisfactory control as it is to use structures in gullies that could be stabilized more economically with vegetation alone. Temporary structures do not require such good materials as permanent structures, nor is so much precision in construction necessary. A permanent structure usually costs more than a temporary structure, and its failure is therefore a greater loss.

TEMPORARY CHECK DAMS

Temporary check dams are used to collect and hold soil and moisture in the bottom of sterile gullies so that vegetation can be established. They may also be used to check temporarily erosion in the gully head or in the channel of a gully until a protective cover of vegetation can be produced. If run-off from the contributing drainage area is diverted from a gully or retained on the watershed or if a gully has advanced to the drainage divide, any check dams used in it would act primarily as obstructions to hold silt and the precipitation occurring on the immediate area. As they would not be exposed to any appre-

ciable amounts of run-off, construction could be simplified considerably. Piles of closely compacted rock and brush are all that is necessary across the bottom of the gully if run-off is negligible.

Where temporary structures have been used to control gullies, it has been found that several low check dams are more desirable than one large dam of equivalent height. Low dams are less likely to fail, and after they silt up and rot away, the vegetation can protect low overfalls at these sites much easier than high ones. A temporary dam should seldom exceed 15 inches in overfall height, and an average effective height of about 10 to 12 inches will be better. By effective height is meant the vertical distance from the original gully bed to the spillway crest of the structure. It requires considerable field judgment to determine the most satisfactory location and spacing for temporary check dams. They may be located on definite intervals and spacings, but usually they are constructed at strategic locations so as to protect and facilitate plant growth at critical points. In this way effective results can be produced with fewer dams.

Temporary dams are used most successfully in gullies that have small drainage areas. The total amount of soil collected by these dams is relatively small, but they hold enough to promote the growth of some vegetation, which in turn forms a barrier that collects more soil. The dams should be constructed far enough into the bottom and sides of the gully to prevent wash-outs underneath or around the ends of the checks. They should also have sufficient spillway capacity to convey run-off at the maximum rate that can be expected during the life of the structure. An apron will generally be necessary to protect the structure from the undermining action of the run-off as it is discharged from the spillway.

The life of temporary structures will, of course, depend on the locality, the quality of the materials, and the construction procedure used, but under ordinary field conditions these structures should last from 3 to 8 years. Spillway capacities are usually designed for rainfall intensities having a frequency of 5 to 10 years. To determine the notch size required, the size and nature of the contributing drainage area can be determined in the field and the probable amount of run-off selected from table 1. The size of the rectangular spillway notch required to handle this run-off can be taken from table 3. As a margin of safety, the depth of the notch should generally be made about 5 to 6 inches deeper than the actual dimensions necessary to conduct the run-off without overtopping. The notches should be made as wide as practical in proportion to the depth in order to avoid unnecessary concentration of the water as it passes over the structure. It is desirable to have the notch length at least several times as great as the depth. With certain types of check dams a curved or a triangular notch is often the most practical.

Suppose it is desired to know the size of a rectangular spillway that will carry a discharge of 32 cubic feet per second. From table 3 it will be noted that it is possible to use several different combinations of depth and length to obtain this discharge. For example, any one of the following notches would be large enough to carry an approximate discharge of 32 cubic feet per second: 1 foot deep by 10 feet long; 1.5 feet deep by 6 feet long; 3.0 feet deep by 2 feet long.

Since it is desirable to spread the water as much as possible in order to avoid undue concentration of water downstream from the structure

and to keep the depth of the water that goes over the dam as low as possible, the best notch size, if the channel width permits, is the one first listed, namely, 1 foot deep by 10 feet long. If a 6-inch margin of safety is added to this depth, the size would be 18 inches deep by 10 feet long.

TABLE 3.—*Approximate discharge capacity* [1] *of rectangular weir notches in small temporary and permanent check dams*

Depth [2] of notch (feet)	Discharge capacity of spillways having a length [3] of—											
	2 feet	4 feet	6 feet	8 feet	10 feet	12 feet	14 feet	16 feet	18 feet	20 feet	22 feet	24 feet
	Cubic feet per second	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*
0.5	2.3	4.5	6.8	9.1	11.3	13.6	15.8	18.1	20.4	22.6	24.9	27.2
1	6.4	12.8	19.2	25.6	32.0	38.4	44.8	51.2	57.6	64.0	70.4	76.8
1.5	11.8	23.5	35.2	47.0	58.8	70.5	82.3	94.1	105.8	117.6	129.3	141.1
2	18.1	36.2	54.3	72.4	90.5	108.6	126.7	144.8	162.9	181.0	199.1	217.2
2.5	25.3	50.6	75.9	101.2	126.5	151.8	177.1	202.4	227.7	253.0	278.3	303.6
3	33.3	66.5	99.8	133.0	166.3	199.5	232.8	266.0	299.3	332.5	365.8	399.1
3.5	41.9	83.8	125.7	167.6	209.5	251.4	293.4	335.3	377.2	419.1	461.0	502.9
4	51.2	102.4	153.6	204.8	256.0	307.2	358.4	409.6	460.8	512.0	563.2	614.4
4.5	61.1	122.2	183.3	244.4	305.5	366.6	427.7	488.8	549.8	610.9	672.0	733.1
5	71.6	143.1	214.7	286.2	357.8	429.3	500.9	572.4	644.0	715.5	787.1	858.6

[1] The discharges that must be designed for may be obtained from table 1 for the different watersheds. For discharges in excess of those shown the length may be increased proportionately if the same head is maintained.
[2] The depth is indicated by *d* in the drawings.
[3] The length is indicated by *l* in the drawings.

The temporary check dams most commonly used in gullies are the woven-wire dam, the brush dam, the loose-rock dam, and the plank or slab dam. Each name indicates the principal material used in the dam. There are numerous variations in the way each of these check dams can be constructed. Satisfactory dams may also be constructed from materials other than those listed or from a combination of those materials. The type selected for use on any particular job depends primarily on the materials available. If several types of suitable materials are available the size and characteristics of the gully will be important considerations in selecting the structure. Often the builder prefers to construct a certain type of dam.

WOVEN-WIRE DAMS

Woven-wire dams (fig. 21) are widely used because of the ease with which they can be constructed, the availability of material, and the possibility of using them in different types of gullies. They are used in gullies of moderate slope and small drainage area. The dam is commonly built in a somewhat crescent or half-moon shape, with the open end upstream. This allows for a longer spillway than is possible on a straight dam and at the same time protects the ends of the dam. The amount of curvature is not fixed by rule. An offset equal to about one-sixth of the width of the gully at the dam site will generally provide sufficient curvature. For example, if the gully is 24 feet wide, the spillway of the dam would be about 4 feet downstream from the abutments. A row of posts is set along the curve of the proposed dam at about 4-foot intervals and 2 to 3 feet deep (fig. 22). One interval should fall near the center of the gully to form the central portion of the spillway. A trench about 6 inches deep and of about

FIGURE 21.—This woven-wire dam is used to aid in establishing vegetation.

the same width is dug along the upstream side of the row of posts. Heavy-gage woven wire is placed against the posts, with the lower part set in the ditch so that 10 to 12 inches projects above the ground surface along the spillway interval. It is desirable to place the coarse mesh on the bottom. The wire should be securely stapled to the posts. If the top of the wire is kept approximately level along the central interval used for the crest of the spillway a much better spreading of water will be obtained as it passes over the structure.

If plenty of rocks are available they may be used for the apron; otherwise brush or sod is generally used. The brush is anchored by pulling the butt ends through the wire mesh, where both the fill and projecting branches will help to hold it. Enough brush is laid to make an apron at least 4 feet long and extending at least 2 feet on each side of the posts that form the level portion of the spillway. Sometimes a tie pole anchored to stakes is placed across the center of the apron to compress the brush. It is desirable to countersink the apron and to use shorter brush near the upper end to produce a shingle effect. A layer of fine mulch underneath the apron is recommended so that a closer bond with the earth can be secured.

To promote rapid filling and to seal the structure, straw, fine brush, or similar material should be packed against the wire on the upstream side to the height of the spillway crest. This should be backed with a well-tamped earth fill of at least a 2:1 slope. Sodding along the spillway crest has proved helpful in preventing channeling along the lip. For spillway dimensions, see table 3. The minimum value of *d* (fig. 22) should be 18 inches.

BRUSH DAMS

Brush dams are best suited for gullies with small drainage areas and with soil conditions that permit the driving of necessary anchor-

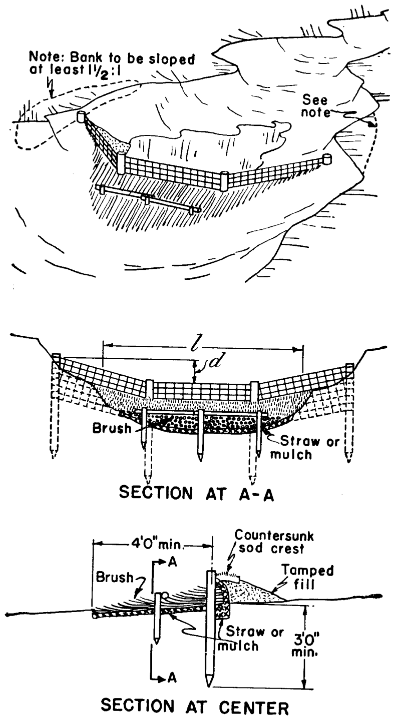

FIGURE 22.—A woven-wire dam.

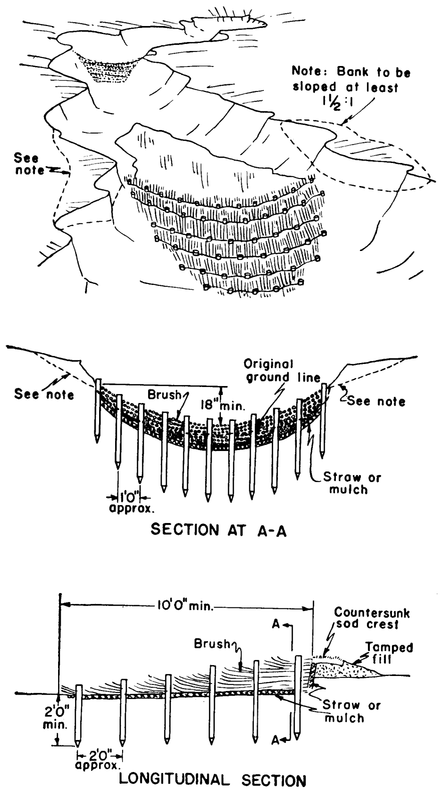

FIGURE 23.—A brush dam in common use.

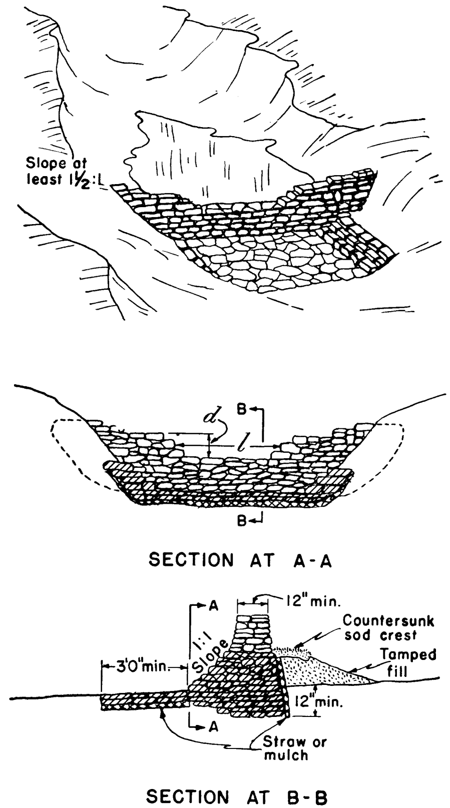

FIGURE 24.—A loose-rock dam.

ing stakes. These dams are cheap and are easy to build. For this reason they are used in most sections of the United States where brush is available. Many kinds of brush dams are in use; the kind chosen for a particular site depends on the amount of brush available and the size of the gully to be controlled. Whatever type is used, it is important that the center of the dam be kept lower than the ends to allow water to flow over the dam rather than around it. The minimum center height for spillway capacity is indicated in figure 23.

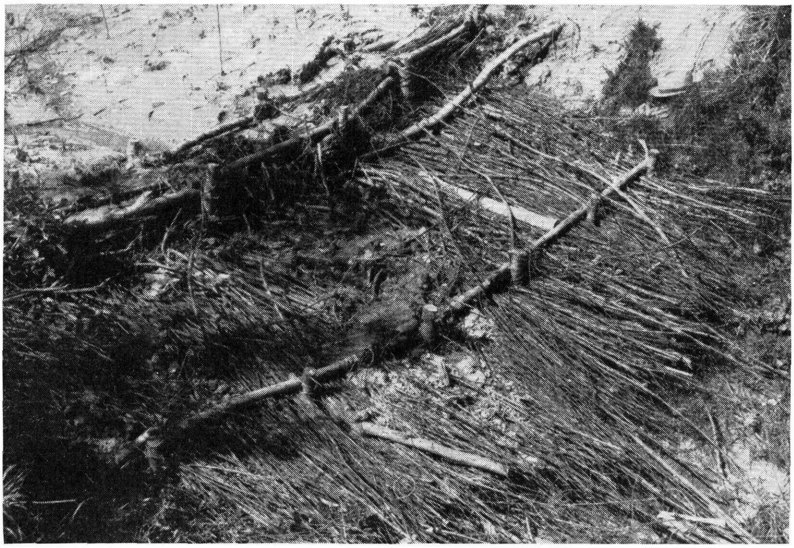

FIGURE 25.—A well-constructed brush dam in a small gully. Note the silt deposit above the structure.

The sides and bottom of the gully for a distance of 10 to 15 feet along the site of the structure are covered with a thin layer of straw or similar fine mulch, which is slightly countersunk in order to form a bond between the structure and the soil. Brush with butts pointing upstream is next packed closely together over the mulch to about one-half of the proposed height of the dam. Several rows of stakes are then driven crosswise of the gully, with the rows about 2 feet apart and the stakes 1 to 2 feet apart in the rows (fig. 25). The stakes should extend up the sides of the gully and should be driven only partly in at first. The brush fill is then completed and heavy galvanized wire stretched along the rows of stakes and fastened to them. When this has been done, the stakes are driven down until the wire firmly compresses the brush in place. Several large rocks are sometimes placed on top of the brush in order to keep it compressed and in close contact with the bottom of the gully. The center of the dam should be made low enough to provide the necessary spillway capacity.

LOOSE-ROCK DAMS

Loose-rock dams (fig. 24) are desirable where plenty of suitable rock is available. They are used in gullies of moderate slope that have small to medium-sized drainage areas. A well-constructed loose-rock dam can be made more durable than the other types of temporary

dams because rock will outlast brush, wire, or slabs. It also has an advantage because its flexibility and weight constantly hold it in contact with the bottom of the gully. The best structures can be built from flat stones, which are commonly known as flagstone. With practice these can be so laid that the entire structure will be keyed together. If round or irregularly shaped rock must be used, the structure is usually encased in woven wire so as to prevent the outside rock from being washed away. Irregularly shaped rocks should preferably be placed in such a way that voids will be reduced to a minimum. If considerable time must be spent to fit the rocks in laying up the dam, it is cheaper and more effective to construct a rubble masonry dam or a concrete dam.

For the loose-rock dam an excavation is made across the gully to a depth of about 12 inches (fig. 24). This forms the base of the dam, on which the laying of the rocks is begun. The rocks are laid in rows across the gully with sufficient overlap to produce a shingle effect and are brought to the required height. The center of the dam is kept lower than the sides to form the spillway. Several large flat rocks countersunk below the spillway so as to be flush with the channel surface will serve as an apron. These should extend at least 3 feet downstream from the base of the dam. For the size of the spillway notch, see table 3.

PLANK OR SLAB DAMS

Plank dams or slab dams (fig. 26) can generally be used in gullies with somewhat larger drainage areas than can the woven-wire or brush dams. They are constructed of planks, heavy boards, slabs, or railroad ties. These dams can generally be constructed with less labor than other types of temporary dams and are particularly applicable in areas where there is appropriate material. If a group of these dams is to be placed in a gully the head wall can readily be constructed to required dimension at the farm shop or some other convenient location and later dropped, as a complete unit, into a suitable trench across the gully.

In building the dam, posts are set in a row across the gully to a depth of about 3 feet and about 4 feet apart. The posts should be so arranged that one of the intervals between posts will occur in the approximate center of the gully to form the spillway. After the posts are set, a narrow trench is dug along their upstream side. The trench is made about 1 foot deep and just wide enough to permit placing of the head wall and a thin layer of straw or grass as a seal. If the planks are close fitting or the slabs overlapped, the seal material may not be necessary. The required spillway notch is cut out after the dam is constructed, or a suitable opening can be left at the top of the head wall during construction. Spillway dimensions are specified in table 3. A well-tamped earth fill is next made against the upstream face of the head wall and brought to the height of the spillway crest. This fill should have a slope not steeper than 2:1 and should extend well up on the gully banks.

The final stage in construction is the apron. If suitable rock is available a rock apron is easy to construct and will give satisfactory results. A brush apron might also be used. Where a plank apron is necessary, an area extending at least 18 inches on each side of the spillway notch and downstream at least twice the effective height of the dam, is excavated to a depth of 2 to 3 inches. A thin layer of

mulch or gravel is spread over this area, on which the apron planks are then placed. One end of the planks is butted against the downstream face of the head wall and the other fastened to a toe log. A baseboard should be placed above the juncture of the apron and the head wall as a protection from water running over the spillway. The side walls of the apron are formed by laying up additional planks parallel to the apron floor and conforming with the slope of the gully sides. If properly laid, the top of the apron floor at the lower end will be flush with the surface of the gully channel. Sod is sometimes used for the apron if the drainage area is small and sod of good quality can be obtained. The life of this type of dam may be greatly increased if the wood used is first creosoted.

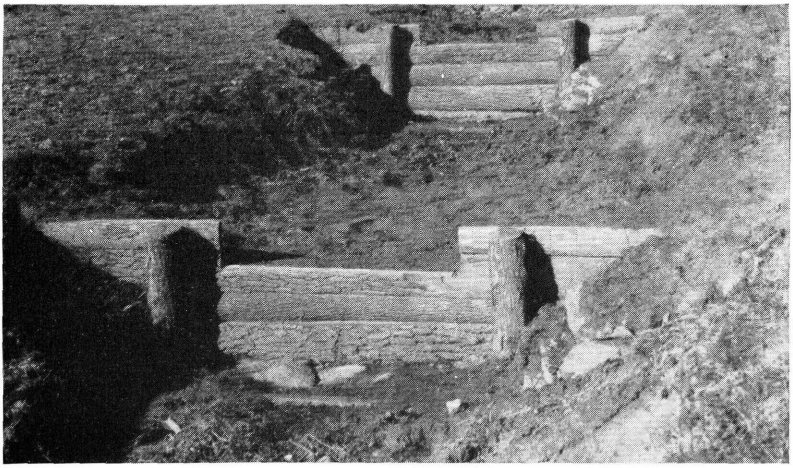

FIGURE 26.—Slab dams in a small gully.

Log and pole dams are sometimes used, but it has been found that the construction cost of these dams is generally higher than that of woven-wire, brush, loose-rock, plank, or slab dams. Some difficulty has also been experienced in getting a good bond between the log or pole structures and bottom and sides of the gully. If proper care is exercised, however, such dams can be used satisfactorily. Poles or logs are in some localities the only material available for the construction of temporary check dams. On favorable sites dams constructed from willow poles have proved satisfactory. The poles should be cut from green willow trees. This dam would be similar to the check constructed from willow cuttings that is described under shrub checks. However, the willow-pole dam is built with a regular spillway notch formed from the poles.

PERMANENT SOIL-SAVING DAMS

Permanent structures are those that are constructed from more durable materials, such as reinforced concrete, masonry, and earth. These structures are used in gullies where temporary dams are either inadequate or impractical. In certain areas rock-filled crib dams and dams constructed from railroad rails have been used. Such structures are usually classified as semipermanent.

Permanent dams are frequently necessary in gullies that must be retained as permanent waterways. Gullies from which the water cannot be diverted are generally very active if their drainage areas are large, and they also are hard to control without some permanent structure. Even a small amount of water going over a 15- or 20-foot overfall will produce enough energy to make the possibility of control by vegetation alone questionable. A gully just beginning to cut back into a large drainage area (fig. 27) should usually be controlled

FIGURE 27.—If uncontrolled, this gully will eventually destroy much valuable land because water from hundreds of acres of farm land drains into it.

by permanent structures in order to protect the area above from further destruction.

The variety of conditions in gullies necessitates the use of several types of permanent structures. Dams with regular notch spillways are usually built in locations requiring low structures. Where the run-off must be brought down from high overfalls, multiple-drop dams, flumes, or drop-inlet dams are usually used. Generally, neither the masonry nor the concrete notch-spillway dam should be used to control overfalls in excess of 8 feet.

The selection of the structure to be used for any particular job is largely a problem of determining the type that will provide the necessary capacity and meet other requirements and yet give the most economical construction costs. Large dams represent a sufficient investment to warrant special precautions. Considerable skill is required to build permanent structures. It is recommended that for the building of concrete or masonry dams with an effective height of over 5 feet the services of a person skilled in design and construction be obtained. If this is not practicable, the plans should at least be reviewed by him. The construction of small earth dams usually does not present the foundation problems encountered with concrete or masonry dams. For this reason earth dams can ordinarily be built to heights of 12 to 15 feet without serious difficulty.

Most States have laws governing the design and construction of dams that exceed certain heights or that impound water beyond a fixed amount. Anyone planning to construct a dam should familiarize himself with all local and State regulations affecting such an undertaking.

To check the advancement of gullies effectively, permanent control structures must be located near enough to the gully head so that the grade from the spillway crest to the ultimate lip of the gully will not exceed the silting grade that can be expected for the particular soil type and cover (fig. 28). This grade may range from ½ to 3 percent or more, depending on the extent to which the future growth of vegetation in the channel above the structure may tend to increase the natural soil gradient. Permanent structures should also be located so that the line of discharge from the spillway will be parallel to the center line of the gully immediately below the dam. This will prevent side cutting of the drainage channel below the structure.

With permanent dams the discharge quantities and velocities are relatively high, so channel grades below or between permanent structures should be almost flat, seldom exceeding a slope of 1 percent unless the channel bed contains sufficient rock to prevent harmful scouring. The stability of a structure is dependent upon stabilized grades in the channel below. Excessive grades lead to the development of channel overfalls, which gradually advance and undermine structures. Steep grades maintained by a plant cover are generally not dependable enough to be relied upon below permanent structures. Excessive downstream grades can be reduced by changing the location of the structure, by excavating and constructing the spillway apron to a lower elevation, or by constructing one or more permanent check dams in the channel below.

It is important that a firm foundation be secured for permanent structures. Generally, wet foundations should be avoided, especially with earth dams. Surface soil and organic matter should be removed from the dam site to get a good bond between the structure and the impervious foundation material. Cut-offs should be extended into the bottom and sides of the gully to provide a more complete seal. An apron of sufficient length, width, and depth to prevent undermining is necessary in the bottom of the gully below the dam. Care must be exercised in selecting and placing the construction materials so that an impervious structure can be assured. Carelessness in construction will result in a weak dam and may lead to failure of the entire structure.

The size of structures to be used is largely determined by the run-off capacity required, the height of overfall to be protected, and the width of gully at the selected site. Since there is generally less danger of failure with low structures and since for low structures somewhat more simple design and construction procedure can be used, it may sometimes be advisable to construct two or more low structures instead of one high structure. The practicability of this substitution is largely dependent on local terrain and conditions in the gully.

The smaller permanent dams should be designed to withstand intensities of rainfall that may be expected to occur once in 10 to 15 years. As the larger permanent dams require greater expenditures, they should be designed for intensities that have frequencies of 25 to 50 years or more. The type of structure used will also have some influence on the selection of the rainfall frequency. Local conditions

and the judgment of the individual in charge of the construction work enter into the selection of design specifications for the various structures. The run-off that may be expected from drainage areas of vari-

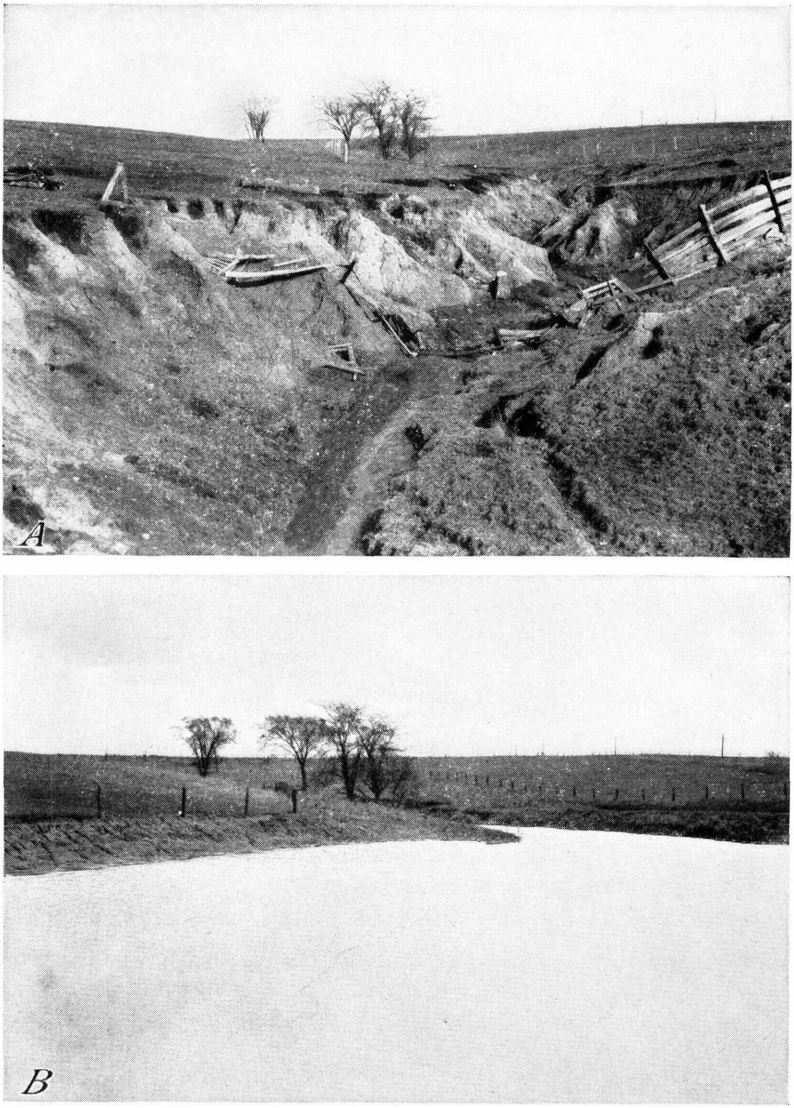

FIGURE 28.—*A*, An active gully head before control work was undertaken. *B*, The same area 1 year later. An earth dam has impounded the water in the reservoir. Waterfall erosion has been eliminated by making the spillway crest of the dam sufficiently high to prevent destructive action at the gully head.

ous sizes under intensities of rainfall of a 10-year frequency is given in table 1. The sizes of rectangular notches required for structures with this type of spillway are given in table 3. In estimating the acreage

of a drainage area the entire contributing area above a dam must be considered.

Good materials and safe designs are essential for satisfactory permanent structures. It is impossible to cover adequately in this bulletin the detailed designs required for all the types and sizes of structures that may be employed to control erosion in gullies. Suitable specifications for only the more common types and smaller sizes have been included.

MASONRY DAMS

Masonry dams are used in areas where good stone is available for masonry work. If only poor rock can be had or if it must be hauled long distances, concrete structures will be more economical. In the neighborhood of good rock quarries, cut-stone masonry may be cheaper than rubble masonry because the latter usually requires more mortar and the masons spend more time in fitting the rock. With a little care, even inexperienced laborers can make a good masonry dam. Precast blocks, bricks, or tile are frequently used for these dams. Any rock used should be hard and durable. Figure 29 shows a rubble masonry dam of standard design. In general the minimum dimension for thickness of side walls, cut-off walls, and apron should be 12 inches. The thickness of the head wall from the spillway crest to the top of the dam should also be a minimum of 12 inches. Below the spillway crest a slope of ½:1 is recommended on the downstream face. In areas subject to severe cold the upstream face of the head wall should have a slope of about 1:10 to diminish ice thrust, and should be made as smooth as practical. In such areas the apron, cut-off wall, and toe wall are often constructed of reinforced concrete as added protection against heaving by frost. An apron length not less than one and one-half times the total height from the apron floor to the crest of the spillway is recommended.

It is important that the cut-off walls at the heel and toe of the dam be carried at least to the depth indicated in figure 29. The head wall should extend well into the banks of the gully. If a thin head wall has been used, it is necessary to add buttresses on the downstream side of the spillway if the spillway

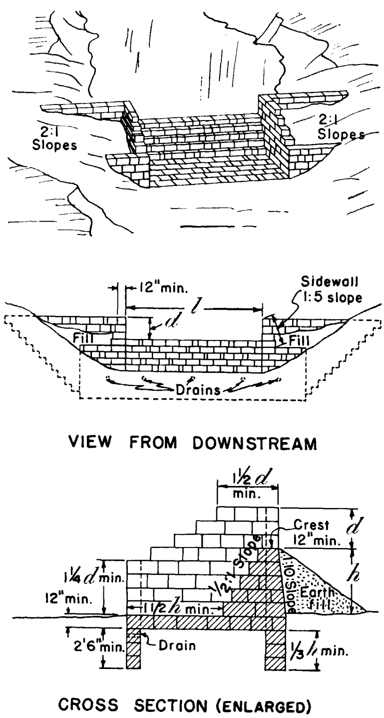

FIGURE 29.—A design for a small rubble masonry dam in which h does not exceed 5 feet.

length (l) exceeds 6 feet or if the height (h) exceeds 5 feet. An earth fill should be made against the upstream face of the dam to the height of the spillway. A large drainage area or unstable soil conditions make it desirable to place riprap below the apron for a distance of 5 to 6 feet. A good quality of mortar of about 1 to 3 mix is suggested for masonry dams. Table 3 gives the required dimensions of the spillway notch.

CONCRETE DAMS

The use of concrete dams is recommended where there is not adequate material for masonry structures. The same general specifications given for masonry dams can be used for concrete dams. Detailed specifications are indicated in figure 30. A good grade of concrete should be used. Information about the use of concrete is given in Farmers' Bulletin 1772, Use of Concrete on the Farm. It is important that reinforcing steel be used in concrete structures. At least ⅜-inch round bars, spaced 12 inches center to center both ways, should be used. The specifications indicated in the drawing are for dams under 5 feet in effective height. For structures exceeding 5 feet in height, a special design is necessary. In case the spillway length (l) exceeds 6 feet, buttresses should be used to brace the head wall. Table 3 gives the dimensions of the notch required for the spillway.

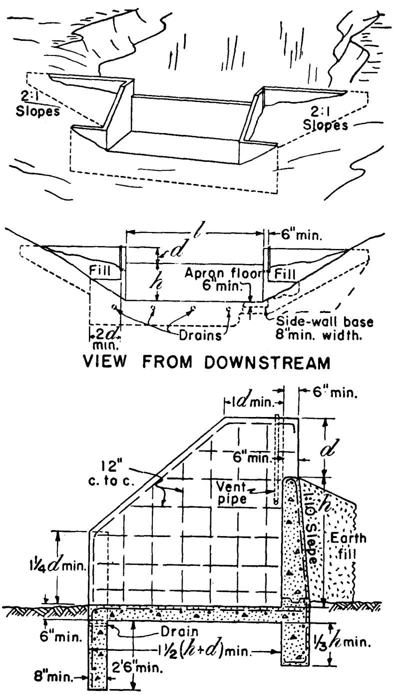

FIGURE 30.—A design for a small concrete dam in which h does not exceed 5 feet.

EARTH DAMS

Earth dams are used in areas where suitable locations and material for the fill can be secured and where a permanent structure is desired. Besides being used strictly for gully control, they are also often used for the dual purpose of controlling gullies and providing a roadway across deep gullies; and they may even provide a farm reservoir or stock pond if the location is suitable and there is need for the water supply. Two types of earth dams are commonly used to impound water for farm ponds. In one the excess run-off is carried around the dam by means of a side spillway (fig. 31), and in the other the excess run-off is carried through the dam by a pipe or culvert. If this culvert has a vertical intake and a nearly horizontal outlet section the struc-

ture is commonly called the drop-inlet, soil-saving dam (fig. 32). In many dams it is desirable to use a combination of conduit through the earth fill and side spillway to bypass the excess run-off. Where this combination spillway is used the conduit through the dam is provided with sufficient capacity to carry only the more common rates

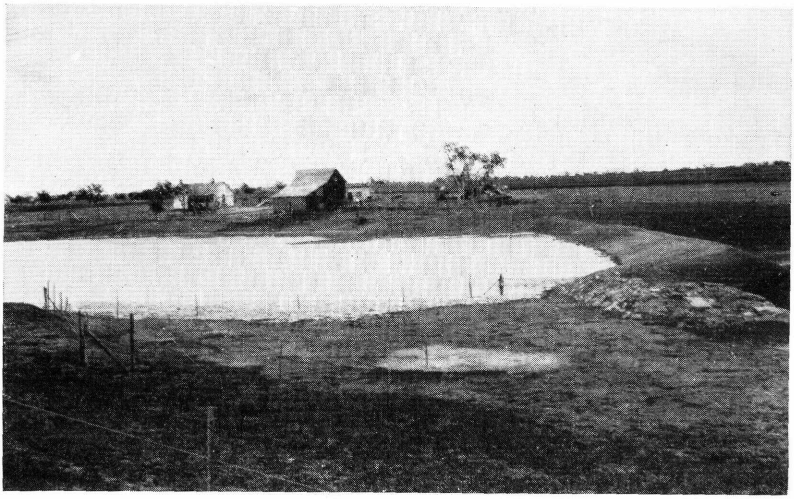

FIGURE 31.—An earth dam with a side spillway. The dam and spillway have been fenced to keep out livestock. This stock pond receives drainage from the barnyard, which is not desirable.

of overflow. The side spillway is constructed with its inlet at a slightly higher elevation than that of the conduit and with sufficient capacity to carry the overflow that cannot be carried through the fill during periods of high run-off. This combination enables the use of cheaper protection, such as vegetation, for the side spillway, because the spillway will be used only occasionally. Using a side spillway is considerably cheaper than carrying all the water through the fill.

The use of side spillways in conjunction with earth dams is limited to locations that have suitable terrain. Usually these spillways are most applicable to low dams, from which the overflow can be lowered to a stabilized grade below the dam without undue expense. Where drainage areas are small and good sod is available, side spillways covered with grass have been used. Where drainage areas are large and spillways of durable material are required the drop-inlet type of spillway is frequently the more satisfactory, especially if overfalls are high. This is particularly true in areas where features of the terrain discourage the use of side spillways or where the earth fill is also to be used as a roadway.

The same general fill specifications ordinarily apply to all types of small earth dams. The best site for the dam is usually at a narrow neck in the channel, if foundation and spillway conditions are suitable and if the gully floor downstream is on a stable grade. The site should be stripped of sod and other foreign material and plowed or

disked crosswise of the gully. It is desirable to place a core wall in a dam to act as a barrier against seepage, and all pipes or tubes through the fill should be provided with ample cut-off collars to prevent seepage. If a pervious foundation (sand, gravel, or shale) is encountered it is usually better to change the location of the dam; otherwise considerable expense may be incurred in providing the necessary cut-offs. The earthen fill should be spread in well-packed layers of not over 6 inches each. It should preferably consist of a mixture of sandy soil and clay, well compacted, and not too dry.

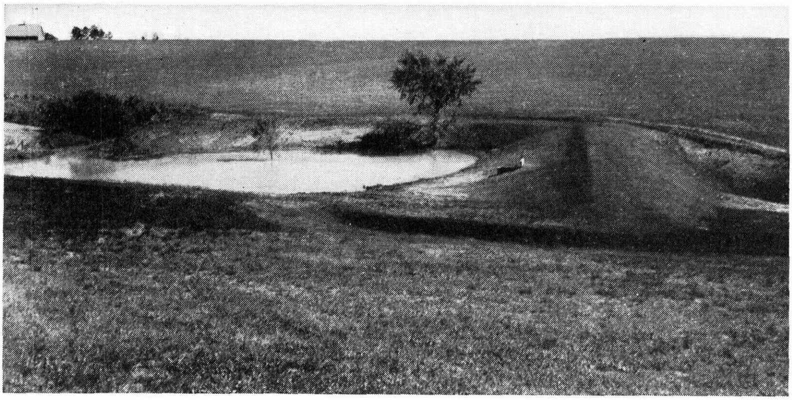

FIGURE 32.—A drop-inlet dam placed in a gully to control further erosion and to reclaim the gullied area above it.

No fill should be made during freezing weather. The side slopes of the settled fill should be not steeper than 2:1 downstream and 3:1 upstream. For ordinary gully-control work a minimum crown width of 4 feet is recommended unless the dam is also to serve as a roadway or reservoir, in which case, top widths of 10 to 20 feet may be required.

The top of the earth fill should be maintained 2 to 3 feet above the maximum height of flow expected through the spillway in order to provide the necessary protection against overtopping. On large earth dams a larger margin of safety should be provided. The fill slopes above the water line and the crown should be seeded to grass. Advantage should be taken of any natural or artificial vegetated spillway available, if only to the extent of using it as an auxiliary spillway in the event of heavy run-off.

Figure 33 shows standard specifications for a soil-saving drop-inlet dam with concrete barrel and riser (reinforcing steel details not shown). The barrel and at least the lower part of the riser must be built before any fill is made. The barrel should rest on a firm foundation, which can usually be otained if an excavation in firm soil is made for the barrel. After the barrel and riser are in place, the fill can be made. The fill around the barrel and riser must be tamped carefully. If the outside walls of the barrel taper slightly from the bottom to the top, the earth will make a tighter contact with them in settling. It is desirable to locate the barrel as near the center of the gully as possible.

On small or medium-sized drainage areas, tile or corrugated metal

pipes are frequently used for bypassing the overflow through the fill. Rounded elbow connections between the vertical and horizontal sections of the tube should be used. Concrete culverts less than 2 feet square are difficult to construct because of the difficulty of removing the forms; so pipe culverts are recommended for small sizes. Table 4 gives culvert sizes recommended in drop-inlet soil-saving dams for various discharges.

It will be noted that round-culvert dimensions are given in table 4 as inside diameter in inches and those for square culverts are given as inside width in feet. For example, it is desired to know the culvert size required for a discharge of 250 cubic feet per second to be carried through a total drop (z) of 20 feet; either a 42-inch pipe culvert or a culvert 3½ feet square will carry the discharge. Usually a reinforced-concrete structure will be more durable and is recommended because of the high total drop here involved. The choice would thus be a reinforced-concrete culvert 3½ feet square.

It is again emphasized that it requires considerable skill to construct

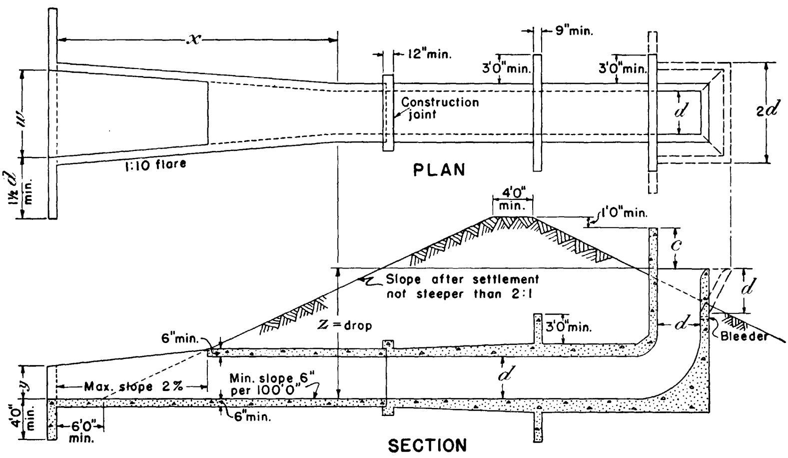

FIGURE 33.—The drop-inlet soil-saving dam with square culvert. The following specifications are recommended: Square culverts should be 2 by 2 feet or larger. If smaller sizes are required, round culverts are used. The outlet width, w, should equal the culvert width, d, plus 6 feet, except for a culvert 2 feet square, in which case, w equals 6 feet. The length x of the flared outlet equals the shorter of $10d$ or 30 feet; c equals the highest expected flood crest in feet over the inlet lip plus one-half foot.

a drop-inlet dam, and it is therefore safer to engage the services of a competent engineer for the construction of at least the larger structures.

FLUMES

Flumes (sometimes called chutes) are used to convey run-off down steep banks or overfalls to a base grade. The steep slopes on which flumes are usually constructed produce high discharge velocities, and care must be exercised to provide necessary apron and grade protection below the structure. Permanent flumes are usually constructed from

TABLE 4.—*Drop-inlet culvert sizes required for discharges of 25 to 550 cubic feet per second*

Total drop(z) (feet)	Type of culvert	Dimensions [1] of culvert for discharging— 25 cubic feet per second	50 cubic feet per second		100 cubic feet per second		150 cubic feet per second		200 cubic feet per second		250 cubic feet per second		300 cubic feet per second		350 cubic feet per second		400 cubic feet per second	450 cubic feet per second	500 cubic feet per second	550 cubic feet per second
		Inches	*Inches*	*Feet*	*Inches*	*Feet*	*Inches*	*Feet*	*Inches*	*Feet*	*Inches*	*Feet*	*Inches*	*Feet*	*Inches*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
5	Round	18	30		36		48													
	Square			2x2		3x3		3½x3½		4x4		4½x4½		5x5		5x5	([2])	([2])	([2])	([2])
10	Round	18	24		36		42		48		48									
	Square					2½x2½		3x3		3½x3½		4x4		4x4		4½x4½	4½x4½	5x5	([2])	([2])
15	Round	15	24		30		36		42		48		48							
	Square					2½x2½		3x3		3x3		3½x3½		4x4		4x4	4½x4½	4½x4½	5x5	5x5
20	Round	15	24		30		36		42		42		48							
	Square					2x2		2½x2½		3x3		3½x3½		3½x3½		4x4	4x4	4½x4½	4½x4½	5x5
25	Round	15	24		30		36		36		42		48		48					
	Square					2x2		2½x2½		3x3		3x3		3½x3½		3½x3½	4x4	4x4	4½x4½	5x5

[1] Sizes are for single culverts, inside dimensions. Dimensions of round culverts are given as diameter in inches. Dimensions of square culverts are given in feet.
[2] When culverts larger than 5 by 5 feet are required, twin culverts are recommended.

concrete or masonry. Wood or metal flumes have been used, and sod flumes (discussed under Vegetation) are commonly used in smaller watersheds. Available material and the degree of permanency desired will determine the most suitable construction material.

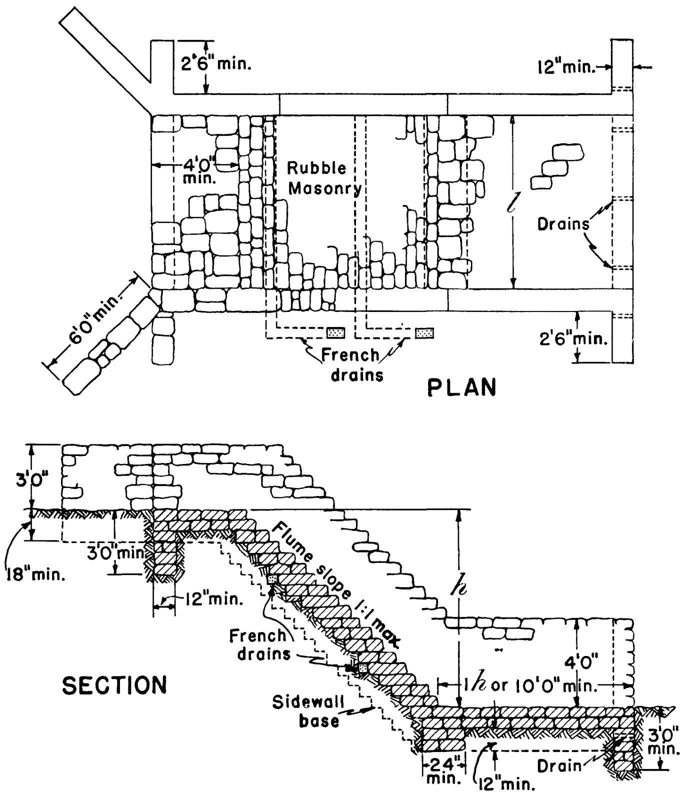

FIGURE 34.—A masonry head flume.

If concrete is used, the slope of the flume should be not steeper than 2:1 to facilitate pouring. A masonry flume may have a slope as steep as 1:1. Concrete and masonry ordinarily make more desirable flumes than wood or metal unless permanency is not essential. Where applicable, sod should be used in preference to any other material because it is the most economical.

Figure 34 shows a standard masonry head flume and figure 35 a flume constructed of concrete. The concrete flume should be reinforced with ⅜-inch round steel bars spaced on 9-inch centers both ways. For either structure it is recommended that both the upstream and the downstream cut-off walls be dug to a minimum depth of 3 feet and that the wing walls extend a minimum of 6 feet into the lead-in dikes on either side of the flume. Side walls should be high enough to

confine completely the maximum flows anticipated during the design frequency. The length of the apron should not be less than the total height from spillway crest to apron floor. The gully channel for some distance below the flume should be on a stable grade; otherwise the structure may undermine. A flume is intended to control waterfall

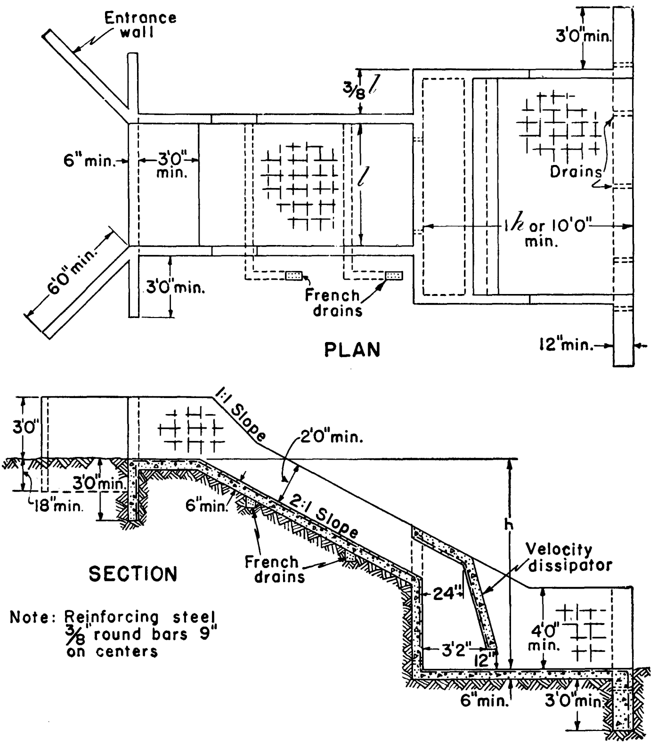

FIGURE 35.—A concrete head flume.

erosion and not channel erosion. In order to assure enough spillway capacity for the flumes, the length *l* indicated in figures 34 and 35 should be a minimum of 1 foot for every 15 cubic feet per second of discharge expected and should have a total length of not less than 4.5 feet.

CULVERT DROP INLETS

Drop-inlet highway culverts are used to combat gully erosion along highways. Excavation for highway culverts is usually below the natural profile of the ground, and when water flows down the drainageway it has to drop in order to pass through the culvert. This drop sometimes is the beginning of a gully of the waterfall type, which, in

eating its way back, may destroy many acres of valuable land on farms adjacent to the highway. If conditions below a culvert are unstable, gullies often eat their way slowly up a watercourse toward the highway and finally undermine the culvert if its substructure is not deep enough to stop further advancement of the gully.

A drop inlet can readily be obtained by constructing a drop box on the upstream end of the existing culvert. The drop box should be built to a height sufficient to prevent further recession of the gully and yet low enough to allow plenty of freeboard for the highway embankment. Before a drop inlet is constructed on an existing culvert it is well to examine the road fill to determine its suitability for the impounding of water. Where it is not desired to impound quantities of water, the drop inlet may be built in stages by adding height as the gully silts up. Wherever possible in suitable locations it is preferable to construct a regular drop-inlet structure at the time the road is being built rather than to wait until a gully is formed and then place a drop inlet on an existing culvert. A drop box on an existing culvert (fig. 36) will not be as efficient as a hydraulically proportioned barrel and riser initially placed.

The drop box may be considered as a broad-crested spillway and the required length determined by selecting the length in table 3 for anticipated run-off and flow depth and then increasing this length by one-fourth. If the entire structure has been designed in accordance with the recommendations for a drop-inlet dam, the size required for different discharges may be taken from table 4. It is often necessary also to place protection on the lower end of a culvert in order to pre-

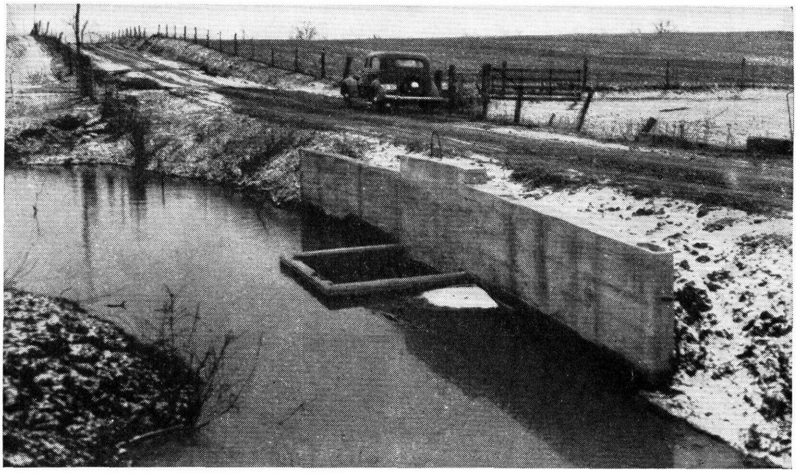

FIGURE 36.—A drop inlet constructed on an existing culvert.

vent gullying. This can be done by using either a suitable drop outlet or by constructing small permanent dams to obtain stabilized grades.

Culvert drop inlets should not be constructed without the approval of the highway officials.

BANK PROTECTION ON SMALL STREAMS

Stream-bank erosion is frequently associated with gully erosion because it is essentially a lateral type of ditch or channel erosion. Gullies often begin at the banks of natural watercourses, especially where the subsurface material is soft and easily worn away, and by waterfall erosion move back into adjacent fields. Portions of valuable bottom lands are frequently damaged by bank cutting that occurs along certain streams, particularly at the bends of winding channels. This cutting may continue even though the stream is on a stable grade. Bank cutting on one side of the stream is usually accompanied by the formation of sand bars or silt deposits on the other, and there is a gradual lateral movement of the main channel. As the process continues, the bends in the channel become more abrupt and the damage to adjacent land more severe.

The numerous factors to be considered and the lack of adequate information makes it impossible to recommend definite control procedure. The success or failure of controlling erosion on stream banks is dependent to a large extent on the judgment of the person in charge. He must have a knowledge of the size of the stream and an appreciation of its destructive force and its flow characteristics. Changing stream flow in one section of the channel will often have a decided adverse effect on the flow for some distance downstream. These resultant effects must be considered, especially when the channel is forced into a new location.

Stream-bank cutting on farms is usually confined to small areas on small streams, some of which flow only intermittently. To control bank cutting on these streams it is generally not necessary to use heavy timber, concrete, or masonry structures, which are ordinarily required for adequate control on large streams and rivers. Suitable trees, shrubs, and grasses are usually sufficient. Before adequate vegetation can be established it is often necessary to use temporary jetties, wing dams, or other obstructions along the eroded bank to check water velocities and start silting. After the bank cutting is checked and sufficient sediment deposited, the necessary vegetation can be planted if sufficient cover is not provided by natural growth.

An important factor in both the prevention and control of stream-bank erosion is the protection of a border strip immediately adjacent to the stream. Instead of plowing to the water's edge or allowing livestock to graze off the protective vegetation, which is found along most stream banks, these areas should be protected. Livestock can be given access to water by lanes fenced to the edge of the stream.

JETTIES AND VEGETATION

If jetties are to be used, the point at which the flow line of the stream intersects the eroding bank is about where the first jetty should be located. Preliminary model tests conducted at the Ohio State University indicated that the intersection point of the eroding bank with a line drawn through the toe of the jetty and parallel to the flow line of the stream should be approximately the midpoint between the first and second jetties. These tests also indicated that the approximate location of each succeeding jetty around the bend would be at a point where a line projected across the toes of the two upper jetties intersects the bank. This procedure of locating jetties is shown in figure 37.

Field observations, as well as the Ohio model tests, indicate that the jetties should point downstream and form about a 45° angle with the bank. The distance that the jetty should project into the stream will depend on how far it is necessary to divert the flow away from the eroding bank in order to secure a normal channel condition.

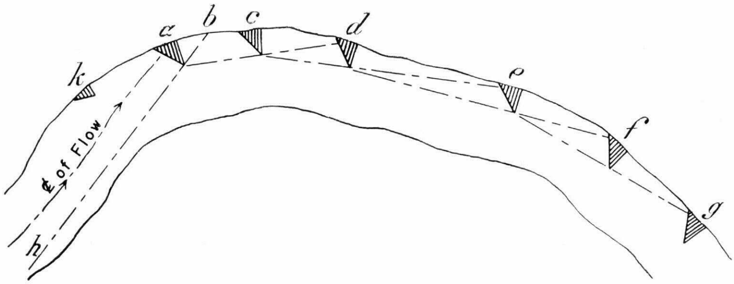

FIGURE 37.—Method of determining location of jetties for stream-bank protection: Point *a*, the location of first jetty, is the intersection of the flow line and the eroding bank; jetty *c* is located by drawing the line *hb* parallel to the flow line and across the toe of jetty *a*; *ac* is twice *ab;* jetty *d* is located by projecting a line across the toe of jetties *a* and *c;* the remaining jetties are located in the same manner as jetty *d;* supplementary jetty *k* is located a distance *ac* upstream from jetty *a* and should be approximately one-half regular size.

A projection of from one-fourth to one-third the width of the stream at flood flow should not be exceeded. If the jetties are extended too far the undesirable channel restriction produced endangers their stability. The top of the jetty should slope downward toward the stream on about the angle of repose desired for the ultimate bank. It has been found advantageous to use low jetties.

The jetties may be constructed of various materials. On shallow, slow-flowing streams, piles of alternate layers of rock and brush have

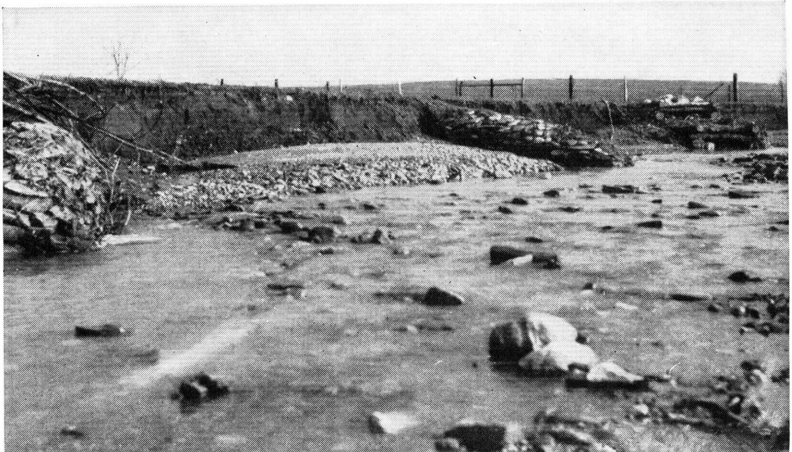

FIGURE 38.—This sausage-type rock jetty is used to protect the stream bank. Note the large amount of material that has been deposited below the retards.

given good results. On faster-flowing streams, the jetties must be well-anchored. Wire-bound, loose rock, which forms a sausage-shaped jetty (fig. 38), has been used extensively. In locations that

FIGURE 39.—In the spring of 1935 this stream bank was sloped, and willow cuttings were placed along the water's edge. The picture was taken about a year later, at which time additional willow cuttings were placed and anchored with small poles and wire, as shown.

FIGURE 40.—A dense growth of willows on the eroding stream bank shown in figure 39. Photographed July 1937.

require heavier structures, rock-filled log cribs or timber piling have been used. Crib jetties should be keyed well into the bank and should extend below the channel bed so as to be protected from undercutting. Those that have undercut at the toe can often be repaired by the use of wire-bound rock.

Willow and cottonwood are desirable trees to plant for stream-bank control. Under certain conditions dogwoods, alder, and other species may also be advantageously planted. The entire bank should be planted, and the plantings should extend as close to the water's edge as possible, provided there is 1 to 2 feet of silt or mud above the low-water level in which they can be established (figs. 39 and 40).

CRIBBING OR RIPRAP

The sharper the bank curvature, the closer the jetties should be spaced. The curvature may be so great, however, that it will require more material to construct jetties than to construct revetment or riprap, which would provide a continuous protection. In making the selection of the most suitable type of protection one must take into consideration the material to be used and the most economical employment of labor in construction. Where only temporary continuous protection is desired, brush matting, loose rock that is bound or anchored with wire, and rock-filled timber cribbing have been used. Where more permanent protection is desired, stone riprap laid in cement mortar on a slope of about 1:1 may be necessary. Continuous mechanical protection should also be supplemented insofar as possible with vegetation.

CHANNEL STRAIGHTENING

The cost of protecting the eroding banks of a winding stream can sometimes be reduced and necessary protective measures minimized by cutting a new channel across ox bows. Careful preliminary investigations should be undertaken when channel straightening is contemplated. The new channel may induce eddy currents that will aggravate the bank cutting and ultimately lead to conditions even worse than those being treated. Furthermore, channel straightening increases channel grades and velocities. Sufficient investigations should therefore be made to determine whether the straightening will lead to the development of harmful channel scouring and overfalls. It is only rarely that it can be justified.

When a new channel is provided it is sometimes necessary to construct a cut-off structure across the old channel in order to force the stream through the new channel. Full-height structures (average flood stage) should be used, which cut off the old channel entirely by projecting from bank to bank. A log crib filled with rock or a crib made of piling and woven wire and filled with rock have been successfully used.

MAINTENANCE OF EROSION CONTROLS

An important and frequently neglected practice in the control of gullies is systematic inspection, repair, and maintenance. Too often erosion controls are installed and then neglected until they become so badly damaged that they are no longer effective. When this happens, practically all expenditures and efforts have been wasted. Installations for control of gullies should be inspected periodically,

especially after heavy rains, to determine whether they are functioning properly or need minor repairs. This is particularly true of vegetative controls during the period when the vegetation is becoming established; at this time it is in its most critical period. The attention given to minor adjustments or repairs during this period often determines whether or not the vegetation will successfully control the gully. Mechanical structures are also more subject to failure when first installed because they do not become thoroughly settled, compacted, or sealed for some time.

It is especially important that all types of erosion controls be protected from livestock (fig. 41). To protect them adequately from

FIGURE 41.—A fence around this gully would have kept the cow out; building a fence is usually less trouble than continually repairing check dams.

damage by grazing and trampling of livestock it is necessary to fence the gullied areas. Hogs particularly should be excluded, for they root up vegetation and damage structures. Vegetation or structures of combustible materials should also be protected from fires. Burrowing rodents occasionally cause failure of structures by digging through or around them.

Even after erosion controls in gullies have been established, some maintenance is necessary in order to assure proper functioning. Diversion ditches may need occasional cleaning out or rebuilding of damaged sections to renew their capacities. In some gullies, vegetation will require cutting in order that water channels may be maintained to full capacity. Debris that collects in the spillways of structures must also be removed at regular intervals, or it may clog the spillways to such an extent that the structure will be overtopped.

Once a gully has been definitely stabilized, it should be able to carry the normal flow of water without danger of further gullying. There is always the chance, however, that excessive concentrations of flow may cause renewed cutting in the old channel. Gullies that have been stabilized for many years may become active again either because

the quantity of water they must carry has been considerably increased or because the original erosion controls have failed to function properly. An increase in rate or amount of run-off may result from changes in land use, cropping, or tillage practices or from an unusually severe storm.

Failure of erosion controls may thus result from improper application, from lack of maintenance, or from some extreme conditions not ordinarily encountered. These factors, potentially capable of disrupting at any time the stability of the gully, should therefore be guarded against to whatever extent is practicable. Any damage incurred should be repaired before it leads to further trouble.

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